INITIAL SPARE PARTS OF THE A400M AIRCRAFT

THESIS

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AFIT-LSCM-ENS-12-20

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AFIT-LSCM-ENS-12-20

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THESIS

Presented to the Faculty

Department of Logistics and Supply Chain Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics and Supply Chain Management

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March 2012

AFIT-LSCM-ENS-12-20

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AFIT-LSCM-ENS-12-20

Abstract

The A400M is a new military transport aircraft, which is designed and built to fill the gap between strategic and tactical capabilities of modern air forces, among which is the Turkish Air Force. To be successful in this endeavor, high aircraft availability is essential. Aircraft availability is affected by selection of spare parts and components availability at the repair facilities. This thesis study seek to determine which spare parts the Turkish Air Force should procure for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts. The Aircraft Sustainability Model (ASM) by LMI is chosen to calculate the essential spare part support. ASM provides the optimal cost vs. availability curve and it is widely used for provisioning, replenishment, and deployment spares decisions. In general, this study develops an ASM model for the A400M aircraft with various fleet sizes, and compares the results to determine the optimal spare part mix. Conclusions which are drawn from the ASM experiments and analysis provides sufficient information to construct the optimal cost vs. availability curve of the A400M aircraft under the Turkish Air Force's maintenance structure. This curve provides critical information for the military decision makers to determine tradeoffs between availability and cost, in order to obtain a better use of scarce resources. The study also provides important insights about the characteristics of the A400M aircraft, such as the optimal availability and the supply cost distribution among the A400M subsystems.

I dedicate this thesis to my mother and father, who offered me unconditional love and support throughout the course of my education life.

Acknowledgments

This thesis would not have been possible without invaluable help of Capt Ferit BÜYÜKGÜRAL and 1st Lt Tuğrul DEMİRBAŞ from the A400M Procurement Project Group from the Turkish Air Force. I owe an immense debt of gratitude to my supervisor, Maj Daniel D. Mattioda for his sound advice and careful guidance. I would also like to thank to Dr. Alan W. Johnson who gracefully provided me the Aircraft Sustainability Model from LMI for his time and cooperation, this project would not have been possible. Finally, for their efforts and assistance, special thanks as well to Dr. William Cunningham and Dr. John Miller for their feedback. To each of the above, I extend my deepest appreciation.

İhsan TOPALOĞLU

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INITIAL SPARE PARTS OF THE A400M AIRCRAFT

I. Introduction

Background

The Turkish Air Force was originally founded in 1911 and recently celebrated its 100th birthday on June 1, 2011. In these 100 years, the Turkish Air Force has always kept itself up to date with its mission requirements and today is no different. Today, the Turkish Air Force is engaged in a meritorious transformation of its infrastructure, in order to meet current and future service requirements.

The Turkish Armed Forces' current modernization programs range from coproduction of medium-sized airlift platforms to locally designed-and-produced technologies. In particular, the Turkish Air Force's aviation assets and information systems are being modernized (Undersecretaries for Defense Industries, 2011). It is stated that Turkey will have earned quite remarkable capabilities with the successful completion of its modernization programs (Enginsoy & Bekdil, 2009). These projects also present numerous opportunities for enhancing the Turkish Air Force's efficiency and effectiveness; however, these capability advancements will take time and resources to implement. The scarce resources should be managed carefully, in order to ensure a smooth transition and success.

The Turkish Air Force is concerned about the impact that aging has on the operational readiness and mission capability of its military transport fleet, comprising mainly C-130 Hercules and Transall C-160. With its aging aircraft inventory, aircraft downtimes are increasing due to scheduled and unscheduled maintenance and supply problems. This results in the lack of an ability to effectively and efficiently meet the future mission requirements. A new military transport aircraft, the Airbus Military A400M, was chosen to join the current military transport fleet and extend the Turkish Air Force's war-fighting capability.

The A400M Program

The A400M program (formerly known as the Future Large Aircraft) is a multinational procurement program between Belgium, France, Germany, Luxembourg, Malaysia, Spain, Turkey, and the United Kingdom for the A400M military transport aircraft, in response to their common military requirements. The program was started as an effort to replace the aging fleets of the C-130 Hercules and Transall C-160 of the participating states. The A400M program aims to deliver the aircraft and the appropriate support at minimal life cycle cost by using a commercial approach (Heuninckx, 2011:3).

The participating states agreed to procure a total of 174 aircraft: Belgium 7, France 50, Germany 53, Luxembourg 1, Malaysia 4, Spain 27, Turkey 10 and the United Kingdom 22 (Airbus Military, 2011:Customer Base). The Turkish Air Force's total orders of 10 aircraft are scheduled to be delivered between 2013 and 2018.

The program prime contractor is the Airbus Military consortium, comprising Airbus, EADS, TAI of Turkey, and FLABEL of Belgium. Airbus is also subcontracted with the management of development activities of the A400M. The necessary support products and services, such as technical documentation, spare parts, ground equipment, training and training aids, and maintenance and support services will be provided by Airbus Military under the prime contract (Heuninckx, 2011:4).

The A400M program is considered one of the key multinational aeronautical projects in Europe. The program implements many improvements both in the area of maintenance and support concepts, and of technological measures. The experience gained by Airbus with civilian aircraft is used for the benefit of military aircraft. The A400M program also seeks a balance between operational availability and life cycle cost (Heuninckx, 2011:23).

The A400M Aircraft

The A400M itself is a new military transport aircraft. It is designed and built to fill the gap between strategic and tactical capabilities of modern air forces, among which is the Turkish Air Force. The A400M is capable of carrying troops and/or cargo loads, performing airdrop, and acting as a tactical air-to-air refueling tanker (Airforce Technology, 2011). It is a technological leap forward compared to its legacy predecessors. The A400M can also travel further and faster than most of the current military transport aircraft. It combines strategic and tactical capabilities with operational flexibility and state-of-the-art technology. A view of the A400M can be seen Figure 1.

The A400M is capable of carrying 37,000 kg (81,571 lb.) of payload; this is significantly larger than its legacy predecessors, the C-130 Hercules 20,000 kg (45,000 lb.) and Transall C-160 16,000 kg (35,275 lb.). The A400M is propelled by four EuroProp International 11,000 SHP TP400-D6 engines. Its four turboprop engines provide a high cruise speed of Mach 0.68 to 0.72, a cruise ceiling of 37,000 ft. The A400M has a range of 2,450 NM with 30,000 kg payload, and 4,700 NM when it is used for ferry flights (Airbus Military, 2011:Specifications).

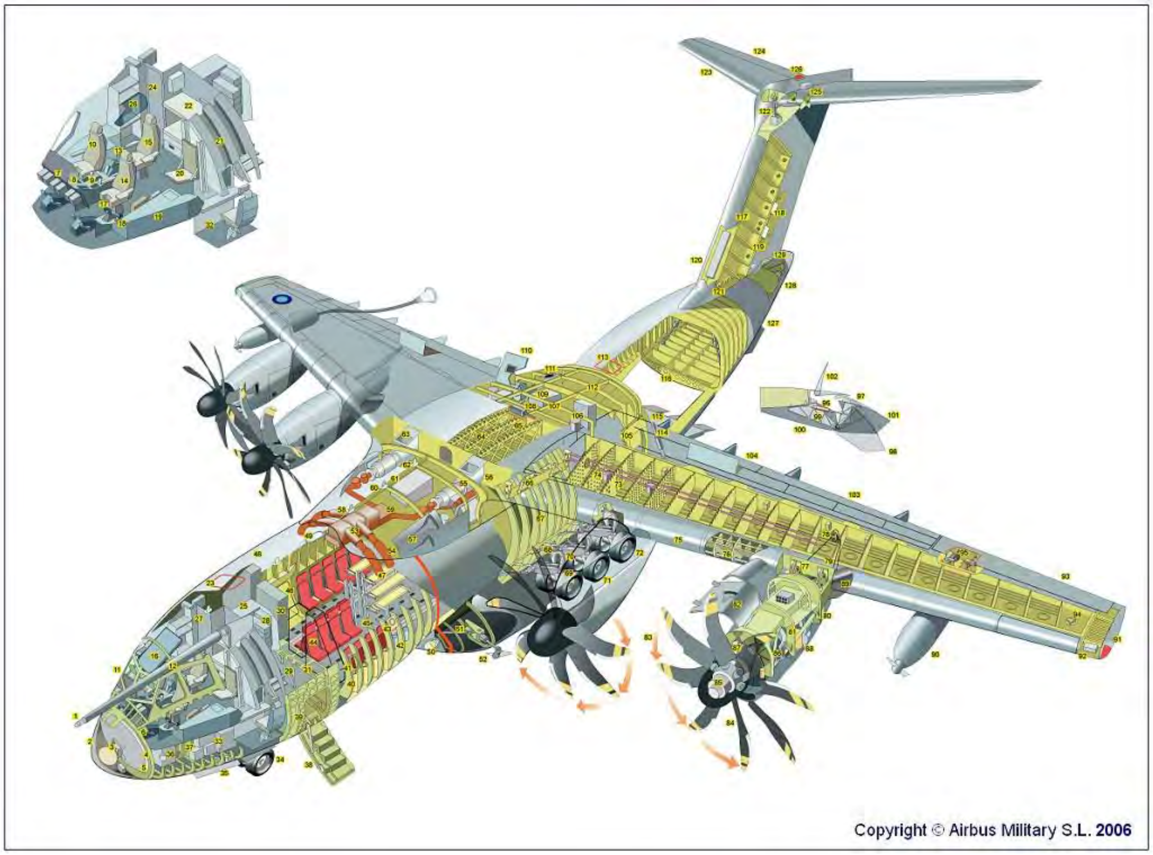


Figure 1: Cutaway View of the A400M Military Transport Aircraft

Tactical military transport aircraft are usually constrained by severe operation environments. However, the A400M is designed specifically to operate from austere airfields with short runways. The A400M can carry helicopters, heavy engineering equipment and armored vehicles, that are too large or too heavy for current tactical military transport aircraft. Its autonomous ground operations capability enables the aircraft to be loaded and unloaded by a single loadmaster without any assistance from ground. This allows the delivery of large amounts of payload into semi-prepared airfields under hostile conditions (Airbus Military, 2011:Capabilities).

The A400M is capable of dropping larger/heavier loads and more paratroops from both high and low altitudes than its legacy predecessors. The A400M is designed for low detectability, low vulnerability and high survivability in order to carry out missions in the most demanding hostile environments. The standard cargo hold configuration of the A400M can be rapidly changed to perform various mission types. The A400M can also act as a tactical air-to-air refueling tanker. With its wide variety of capabilities and large operating flight envelope, the A400M provides a tremendous operational flexibility that no other military transport aircraft can offer (Airbus Military, 2011:Flexibility).

The A400M has inherited state-of-the-art and cost-effective technologies from the latest Airbus aircraft models. With the help of two independent fly-by-wire control systems, the A400M provides excellent control to its pilots. Extensive use of composite materials reduces structural fatigue, maximizes structural life and reduces concerns about corrosion on major components. In order to gain better lift distribution and improved handling, the A400M is designed with engine rotation "down between engines" (the inboard and outboard propellers turn in opposite directions with blades rotating downward between the engines, as seen in Figure 1). This creates more efficient wing design and savings in weight. The cockpit is loaded with state-of-the-art control systems, head-up displays, low level flight autopilot and automated defensive aid systems in order to reduce pilot workload and let pilots focus on the mission (Airbus Military, 2011:Technology).

Problem Statement

The Turkish Air Force's war-fighting capability is determined by its ability to project armed forces onto theaters of operation, quickly and effectively. Air mobility is vital in achieving this objective. The Turkish Air Force's military transport fleet is responsible for carrying personnel, equipment, and supplies to any trouble spot rapidly and efficiently. To be successful in this endeavor, high aircraft availability is essential.

Aircraft availability is a metric that has become the cornerstone for maintenance metrics (Air Force Logistics Management Agency, 2009:31). In simple words, availability is the ratio of system up time to total time. Availability of the military aircraft is critical for mission readiness and it is negatively correlated with down time. System down time, the complement of system up time, is mainly influenced by failure frequency and repair time of the system. System down time is also affected by selection of spare parts and components available at the repair facilities (Ebeling, 2010:219).

Availability is an important characteristic of the system, because it measures the combined effect of the failure (reliability) and the repair (maintainability) process (Ebeling, 2010:2). Reliability is mainly determined by design of the system and decisions made during feasibility, definition and specification phases. Reliability may not be altered after initial phases, or may be tremendously costly to improve. On the other hand, maintainability of the system depends on not only the system reliability but also the maintenance infrastructure associated with the fleet. Maintenance infrastructure depends on several other parameters, such as maintenance workforce, spare parts availability and administrative decisions (Andresen & Williams, 2011:2).

Logisticians have always been faced with the challenge of achieving both high aircraft availability and low life cycle cost. Availability can be improved by careful allocation of resources. The supply support is a major driver in performance and cost. Lack of spare parts can easily ground the aircraft, regardless of maintenance capabilities. Insufficient provisioning of critical items may result in vital system downtime and low aircraft availability. However, spare part support is also costly. A balance has to be sought between aircraft availability and the cost of spare parts. The right amount of spare parts should be procured and stored to achieve the optimal maintenance levels. In order to be cost effective, the supply support should also be tailored to the Turkish Air Force's mission requirements and maintenance infrastructure.

Availability improvements do not come cheap. The availability and the cost of spare parts are highly correlated. Availability improvements can be achieved by procuring extra spare parts. The cost vs. availability curve shows how the cost changes with aircraft availability. The curve represents the lowest cost of achieving certain availability. Less than optimal solutions may occur due to poor selection of spare parts (Johnson, 2010:Lecture 12). An example cost vs. availability curve can be seen in Figure 2. On this figure, the vertical axis shows aircraft availability, while the horizontal axis shows the associated cost with this availability level. The curve is created by calculating the cost for each aircraft availability level. Each point on the curve represents the cost of the optimal spare part mix for the corresponding availability rate. Therefore, any point on the left of the curve is not achievable, while any point on the right of the curve shows poor selection of spare parts. As shown in Figure 2, the curve does not follow a linear line between 0% and 100%; instead, it starts with a low slope value, shows increasing marginal rate of return, then follows a linear line, and ends with a diminishing marginal rate of return. Quantification of the curve reveals enough information to conduct marginal cost analysis. The military mission requirements are always subject to change and by using the cost vs. availability curve, the military decision makers can make tradeoffs, in order to obtain a better use of the scarce resources.

The cost vs. availability curve enables important tradeoff opportunities between aircraft availability and the cost. Great amounts of resources can be saved with these tradeoffs. In an example spare part procurement project, Norwegian Defense Logistics Organization was able to reduce the cost of spare parts by 58.7% with only 16% decrease in aircraft availability, compared to the supplier's initial suggestion (Tysseland, 2009:22).

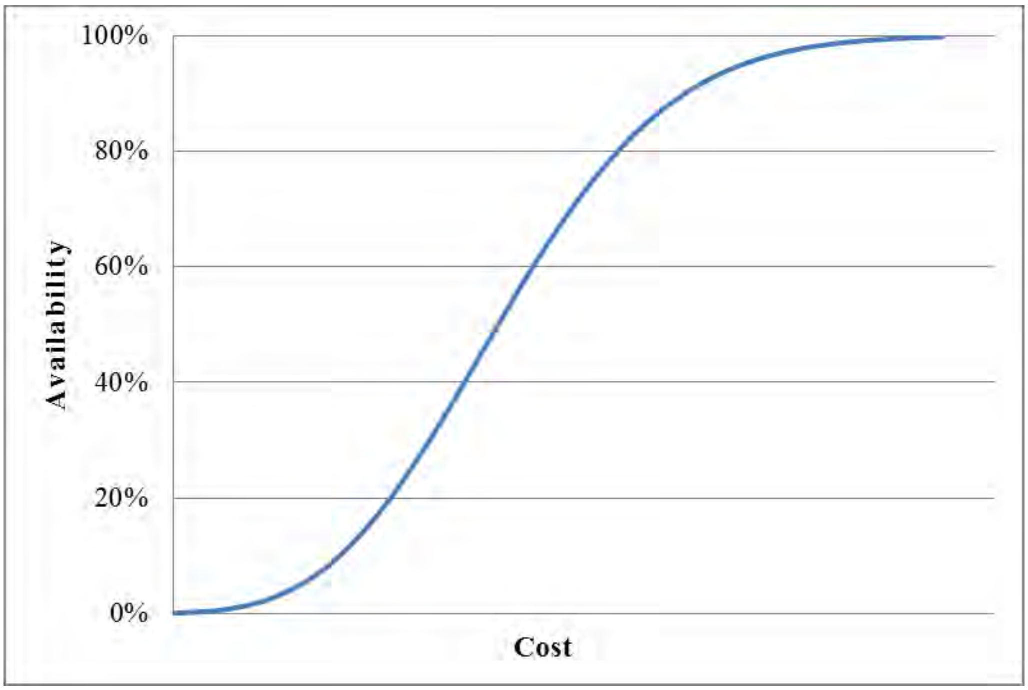


Figure 2: An Example Cost vs. Availability Curve

Research Question

The A400M comes with technological improvements and increased component reliability. It also applies modern maintenance and support concepts to improve aircraft availability and reduce life cycle cost (Heuninckx, 2011:1). The Turkish Air Force's total orders of 10 aircraft are scheduled to be delivered between 2013 and 2018. The A400M is expected to extend the Turkish Air Force's ability to transport personnel, equipment, and supplies onto theaters of operation. In order to be successful in this goal, high aircraft availability of the A400M has to be achieved by sufficient spare part support. The necessary spare parts should be obtained and stored at repair facilities prior to the aircraft deliveries. However, spare parts are expensive to procure, store and manage. A balance has to be sought between aircraft availability of the A400M and the cost of spare parts. The Turkish Air Force initially aims to achieve 80% aircraft availability for the A400M. Important insights and tradeoff opportunities can be gained by researching the characteristics of the A400M. Hence, this research seeks to answer the following question:

Which spare parts should the Turkish Air Force procure for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts?

Investigative Questions

Answering the research question requires several other investigative questions to be answered.

1. What is the cost vs. availability curve of the A400M fleet with the Turkish Air Force's maintenance structure?
2. What is the optimum aircraft availability of the A400M? Is the aircraft availability goal of 80% viable?
3. How does each aircraft delivery affect the supply support cost and the cost vs. availability curve?
4. What is the supply cost distribution among the A400M subsystems?

Assumptions

This research is founded on the key assumption that the aircraft availability is determined only by the spare part support. Procurement of a new aircraft platform is a delicate process and requires the expertise of multiple disciplines. However, this research is established on a logistician perspective.

Aircraft availability is assumed to be determined only by the spare part support that will be provided by the Turkish Air Force. Even though, in real life the availability of an aircraft platform depends on several parameters, such as maintenance work force, ground equipment, training, operation environment and more. This key assumption gives us the ability to perform relevant inventory management techniques to gain insights of the characteristic of the A400M. Reliability engineering has a field of its own and reliability of the A400M is not considered in this study.

The A400M program is currently in the initial logistics provisioning phase. The Turkish Air Force is gathering the necessary support products, such as technical documentation, spare parts, ground equipment, training and training aids. The maintainability of the A400M will be affected by this adoption period following a learning curve.

Local production of the spare parts, interaction with other aircraft platforms, changes in the mission requirements and the technology transfer will affect the maintainability and even the reliability of the A400M. The maintenance capabilities will change over time notably. In order to capture the effects of the spare part support, the reliability and the maintainability of the A400M were assumed constant.

Determining the essential spare part support requires detailed information about operation environment, maintenance structure, and historical reliability data. However, there is no historical data yet available for the A400M. To conduct this research, Airbus's reliability estimates are used.

Further assumptions are also made, due to complexity of supply systems and the lack of publicly accessible data. The planning horizon is assumed to be 5 years, with the aircraft delivery schedule shown in Table 1. It is assumed that the A400M will be stationed in a single base and the aircraft utilization will be stable, in order to represent the peace time. It is also assumed that initially the Turkish Air Force will not have any spare part repair capability and this service will be provided by Airbus entirely (with the order and shipment time of 8 days).

Table 1: Assumed Delivery Schedule of the A400M

Year	Delivery Quantity
2013	1
2014	2
2015	4
2016	2
2017	1

Methodology

Spare part support is more complex than many people realize and it is often performed poorly, even by world-class companies (DeCastro, 2006:115). Traditional inventory models focus on individual items. Stock levels are determined on an item-by-item basis, without considering their effects on the system performance. The item approach performance is measured by fill rate, the percentage of demands satisfied off-the shelf. Inventory managers try to maintain sufficient levels of inventory to achieve specified fill rate. In the item approach, the system availability is the result of many item based decisions. The item approach results in inefficient spare part support and uncontrolled system performance (Johnson, 2010:Lecture 12).

However, spare part support is used to assist a maintenance crew in keeping the system in operational condition. Every spare part has a different bearing on the system performance, due to its importance, price, supply source, failure and repair characteristics, and many other factors (DeCastro, 2006:115). Therefore, inventory stock level of individual spare parts should be set to optimize the overall system performance. The system approach can generate an optimal cost vs. availability curve, which then can be used to obtain the same level of performance with less inventory investment (Johnson, 2010:Lecture 12). The system approach is widely used in Readiness-Based Leveling (RBL) of the United States Air Force (Fulk, 1999:3) and it is still in use (Johnson, 2010:Lecture 20). The RBL is considered as the cornerstone for setting recoverable parts levels in the supply system (Fulk, 1999:3).

In this study, the Aircraft Sustainability Model (ASM) is chosen to determine the essential spare part support for the A400M. The ASM is a tool created by Logistics Management Institute (LMI) for the United States Air Force. It uses the system approach to provide a wide range of inventory (spare parts) decisions. A typical implementation of the ASM results in up to 25% saving in the inventory investment. It is capable of calculating optimal spares (both repairable and consumable items) requirements for a single aircraft type with respect to maintenance structure. The ASM optimizes the spare part support by using the system approach. Spares are selected and put into a shopping list ordered by their benefit-to-cost ratio. The shopping list method ensures the greatest marginal improvement in aircraft availability per monetary unit (Slay and others, 1996:2-16). The ASM provides the optimal cost vs. availability curve and it is widely used for provisioning and replenishment decisions by the United States Air Force (Johnson, 2010:Lecture 20).

Summary

This chapter has provided a brief background for the A400M project and the purpose of this study. The A400M aircraft is a military transport aircraft that is capable of carrying troops and/or cargo loads, performing airdrop, and acting as a tactical air-to-air refueling tanker. The A400M is a technological leap forward compared to its legacy predecessors. This study seeks to find the optimum supply support for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts.

The rest of this paper is structured as follows: Chapter II is a literature review that will explain the concepts that are related to this study and discuss relevant inventory management techniques that are used to provide information about aircraft availability based on spare part levels. Chapter III will explain the methodology used to determine the optimal spare part mix for the A400M. Chapter IV will present the results of this study. Finally, Chapter V will discuss conclusions and observations drawn from the results, as well as any future research opportunities.

II. Literature Review

Chapter Overview

A literature review was performed to assess the feasibility of a research on proper spare parts selection for the A400M. This chapter begins by defining the aircraft availability. An analysis of system down time is presented to display the factors affecting the aircraft availability. A comparison between civilian and military environments is provided to explain why it is harder to acquire the balance between aircraft availability and cost in military. The chapter continues with a brief introduction to inventory management systems, unique aspects of maintenance inventories, and common inventory performance measures. Benefits of system-approach are explained and repairable inventory systems taxonomy is provided. The chapter concludes with an overview of the Aircraft Sustainability Model (ASM).

Aircraft Availability

The main mission of an air force is to defend its Nation. This ability is directly related to availability of air force aircraft. All aircraft platforms must be in operationally available condition at any time a mission demand may arise. "Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time." (Department of Defense, 2005:1-1). How many aircraft you have has no importance, if none of them can fly when you need them. In this sense, Aircraft availability has become the cornerstone for maintenance metrics (Air Force Logistics Management Agency, 2009:31). Availability is an important characteristic of the system, because it measures the combined effect of the failure (reliability) and the repair (maintainability) process (Ebeling, 2010:2). In simple words, availability is the ratio of system up time to total time. This can be seen in Equations 1 and 2.

$$Availability = \frac{Up\ Time}{TotalTime} \tag{1}$$

or

$$Availability = \frac{Total\ Time - Down\ Time}{Total\ Time} \tag{2}$$

When an aircraft is ready for the mission, it is considered as up or Mission Capable (MC). Aircraft are agile technologies of our time and they consist of multiple systems. Things fail and maintenance has vital importance on mission capability. An aircraft requires both preventive and corrective maintenance to be mission capable. Modifications are also necessary to keep aircraft up to date. When an aircraft is either in maintenance or in depot for modification, it is considered as down or Not Mission Capable (NMC).

As it can be seen in the equation above, availability of the system is negatively correlated with system down time. System down time is mainly influenced by failure frequency and repair time of the system. System down time is also affected by selection of spare parts and components available at the repair facilities (Ebeling, 2010:219). It is obvious that aircraft availability can be limited by lack of spare parts. Supply chain problems can easily cause delays and extend the system down time by days, weeks, and even by months. The importance of spare part support is recognized by air forces and carefully monitored. This reduces the downtime and increases the aircraft availability (Buderath, 2011:15).

Aircraft availability is not independent from supply support cost. In fact, aircraft availability and the supply support costs are highly correlated. The cost vs. availability curve shows how the supply support cost changes for a given system. The curve represents the best spare part support with the lowest cost that enables sufficient maintenance levels to achieve the desired aircraft availability.

The curve enables important tradeoff opportunities between aircraft availability and the cost. Poor selection of spare parts may result in far than optimal solutions (Johnson, 2010:Lecture 12). With the help of the curve information, the Turkish Air Force may decide it is more beneficial to decrease the A400M availability and relocate resources for a better use. In an example spare part procurement project, Norwegian Defense Logistics Organization was able to reduce the cost of spare parts by 58.7% with only 16% decrease in aircraft availability, compared to the supplier's initial suggestion (Tysseland, 2009:22).

Analysis of System Down-Time

The United States Air Force Logistics Management Agency (AFLMA) defines aircraft availability as the ratio of Mission Capable (MC) hours to Total Active Inventory (TAI) hours. Non Mission Capable (NMC) hours or system down time is defined as the summation of five subcomponents: the not mission capable due to maintenance (NMCM) hours, the not mission capable due to supply (NMCS) hours, the not mission capable due to both mission and supply (NMCB) hours, the depot level modifications (DEPOT) hours, and the unit possessed but not reported (UPNR) hours (Air Force Logistics Management Agency, 2009:31). These five reasons of down time provide insight about aircraft availability. This can be seen in Equations 3 and 4.

$$Availability = \frac{MC}{TAI} \quad (3)$$

or

$$Availability = \frac{TAI - (NMCM + NMCS + NMCB + DEPOT + UPNR)}{TAI} \quad (4)$$

A breakdown of aircraft time is helpful to comprehend the components that affect aircraft availability (Andresen & Williams, 2011:2). As seen in Figure 3, aircraft time consists of several components, mainly system up time and system down time. When the aircraft is up, it is considered as mission capable. When the aircraft is down, it is either in maintenance or under modification. Depending on the characteristics of the maintenance actions to be performed, maintenance process can be performed on a scheduled (planned) or unscheduled (interruptive) manner. The total maintenance time is mainly influenced by failure frequency (reliability) and repair time (maintainability) of the aircraft. However, sufficient supply support is also essential for these maintenance activities (Ebeling, 2010:219). Extensive delays may occur in the maintenance process, due to a lack of spare parts. This increases the total system down time and decreases the aircraft availability.

Historical data analysis can provide valuable information about aircraft down time, such as aircraft down time drivers. Such an analysis for a modern range transport aircraft shows that 16% of the aircraft down time was associated with supply related problems (NMCS and NMCB), as seen in Figure 4 (Andresen & Williams, 2011:4). The analysis shows that unit-level unscheduled maintenance (NMCMU) accounts for 41% and depot maintenance (DEPOT) accounts for 33%. The remainder 10% of down time is associated with scheduled maintenance (NMCMS) activities.

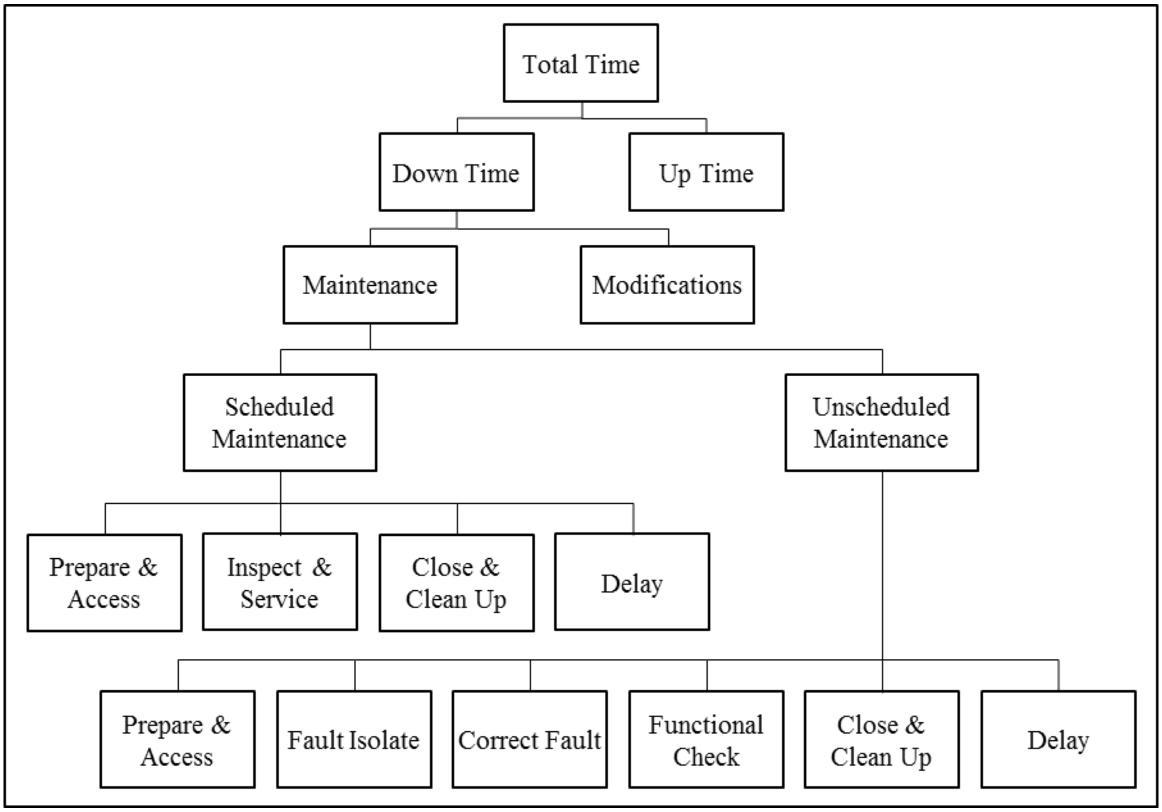


Figure 3: Breakdown of Aircraft Time (Andresen & Williams, 2011:2)

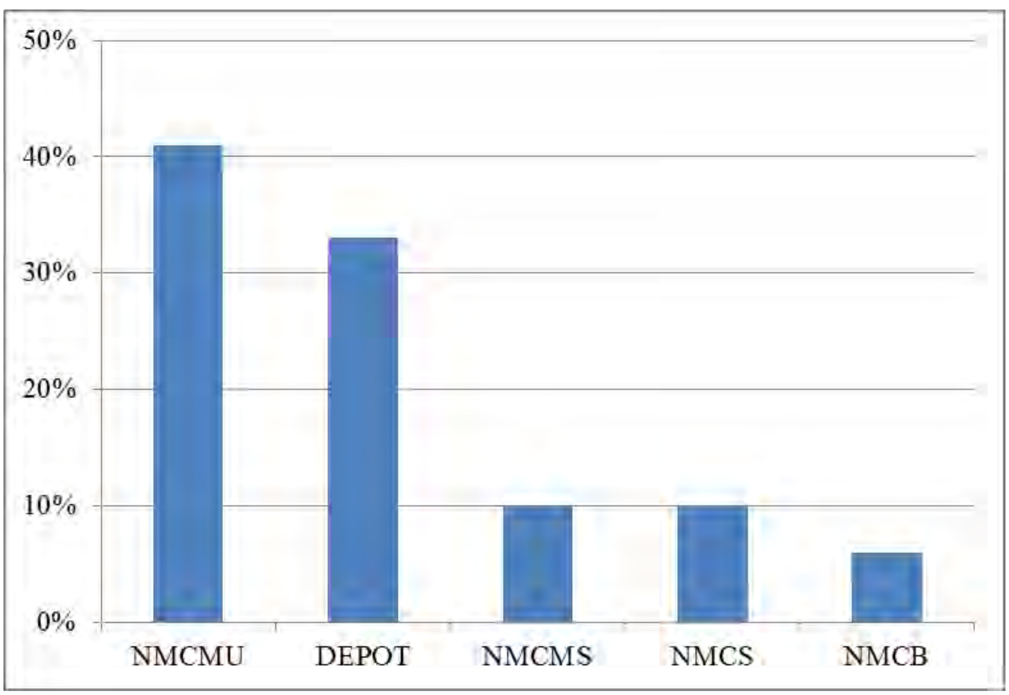


Figure 4: Aircraft Down-Time Drivers (Andresen & Williams, 2011:4)

Factors Affecting Aircraft Availability

The most significant factor in determining the aircraft availability rates is the total mission capable hours, which used to be the most commonly used metric until 2004 (Fry, 2010:10). There are many factors related to the total mission capable hours, such as manpower, operational tempo, spare part issues, and others. However, most of these factors can be grouped into one of the following categories: aircraft reliability and maintainability, personnel, environment, aircraft operations, logistics operations, and of course funding (Oliver and others, 2001:32).

Aircraft availability is mostly determined by aircraft reliability and maintainability. It is the combined effect of these two. Reliability is defined as the probability of a nonfailure over time, under stated operating conditions (Ebeling, 2010:5). The inherent reliability metrics, such as Mean Time Between-Failure (MTBF), are influenced by the system's complexity and technology. Reliability dictates the failure frequency of a component or system. On the other hand, maintainability is defined as the probability of repair in a given time, when maintenance is performed according to prescribed procedures (Ebeling, 2010:5). Maintainability dictates the inherent repair time of a component or system. Maintainability depends on not only the aircraft reliability but also the maintenance infrastructure associated with the fleet. The observed repair time depends on the availability of maintenance resources, such as maintenance personnel, ground equipment, spare parts and many others. Aircraft reliability and maintainability are mostly determined by decisions made during the design phase of the aircraft.

The environment and aircraft operations play a major part in aircraft availability. Increases in operational and personnel tempo negatively affect both equipment and personnel (Oliver and others, 200134). Increased aircraft utilization and deployments may also cause additional reliability and maintainability problems. This is especially true for military transport aircraft since they have a greater likelihood of critical failure occurring in unsupported remote locations (Andresen & Williams, 2011:3).

Logistic operations have significant influence on the aircraft availability. Some of the factors include inventory levels, repair times, order and shipment times, material shortages, and diminishing manufacturing sources (Oliver and others, 2001:33). It is obvious that aircraft availability can be limited by lack of spare parts. Supply chain problems can easily decrease the aircraft availability. Spare part demand fluctuates due to environment and aircraft operations. Safety stocks have to be kept, in order to accommodate this demand change over time. Appropriate level of spare part inventory, repair capability and capacity should be obtained, in order to enable desired maintenance levels (Johnson, 2010:Lecture 12). The importance of spare part support is recognized by air forces and carefully monitored (Buderath, 2011:15).

Funding provides the essential resources to achieve the desired aircraft availability. Funding does not create aircraft availability, but enables it. Both maintenance and supply resources are provided by funding, and they are both necessary to bring aircraft availability. Limited funds should be allocated properly among competing requirements (Oliver and others, 2001:34).

Civilian vs. Military

The way civilian companies address availability differs from military at a fundamental level. Civilian companies perceive flights as a revenue source. The mission, for a civilian aircraft is to perform as many flights as possible, in order to generate revenue. Civilian aircraft are designed to perform up to 4 or 6 missions per day. A civilian aircraft is used for more than 2,000 Flying Hours (FH) per year per aircraft, or approximately 6 FH per day. Compared to civilian aircraft, military aircraft are mostly underused. For example, the expected usage of the A400M is 650 FH per year per aircraft. However, when the need for a military aircraft arises, the maximum availability is expected due to vital consequences. Civilian aircraft are designed to endure malfunctions during flight missions, so that aircraft are only repaired during the night time. In this sense, civilian companies use the Operational Reliability (OR) to measure the health of the fleet, which is defined as the percentage of flights without mission loss. A mission loss will be declared if the mission departure is delayed more than 15 minutes for technical reasons or if the mission is interrupted (on ground or in flight) due to technical reasons. Operational reliability is equivalent to the military term Mission Reliability. The A400M contract requires an Operational Reliability of 98.7% (Heuninckx, 2011:10).

The difference between civilian and military usage concepts leads to different availability metrics to measure the health of the fleet. For a civilian company, availability is directly related to revenue. An increase in availability leads to an increase in revenue. The balance between availability and life cycle cost can be obtained on the financial balance sheets. Availability improvements can be made, as long as the revenue increase exceeds the total cost increase. Companies, who fail to achieve the balance, will soon face bankruptcy (Heuninckx, 2011:10). In the military, the issue of financial interest is replaced by national security. Failure to achieve the operational requirements may result in fatal consequences. The balance between availability and life cycle cost is harder to achieve, and yet possible. To be successful in this endeavor, scarce resources should be managed carefully. The military decision makers can make tradeoffs between availability and cost, in order to obtain a better use of the scarce resources. The cost vs. availability curve provides the critical information to determine these tradeoffs.

Availability Improvements in the A400M

The A400M program applies modern maintenance and support concepts to improve aircraft availability while reducing life cycle cost. To be successful in this endeavor, the A400M is managed by a commercial approach. Under the commercial approach, the prime contractor has the freedom to design and manufacture a product that meets the contractual requirements of the participating states. The scheduled maintenance of the A400M is reduced to minimum maintenance activities that are absolutely necessary for the safety and economics of operations. This is enabled via onboard systems diagnostic integration and damage tolerant design. In a period of 5 years, the scheduled maintenance down time of the A400M is expected to be 50 days, which is significantly less than C-17 Globemaster III (150 days) and Lockheed Martin C-130J Super Hercules (120 days). Reduced scheduled maintenance directly translates into increased aircraft availability. The A400M program contains extensive use of on-condition maintenance, in order to avoid premature replacement of parts. With the application of a Maintenance-Free Operating Period (MFOP) concept, the A400M provides a guaranteed deployment reliability of 90% for a deployment of 15 days. The support concept of the A400M program includes different levels of work distribution between the military services and civilian industry. Some participating states even consider relying on a spare part leasing option. Besides modern maintenance and support concepts, the A400M program also applies technological measures to improve aircraft availability. All design information of the A400M is stored in a digital mock-up. Contractual supportability analyses are conducted with the digital mock-up of the A400M. These analyses include accessibility, ease of removal, maintenance tasks, ground support equipment, tooling, and procedure and manpower/duration requirements. Finally, the A400M uses highly reliable components and system redundancy to increase availability while reducing the life cycle cost (Heuninckx, 2011:8-22).

Inventory Theories

Inventory is one of the most expensive assets. It is a well-known fact that good inventory management is crucial for operations. It provides protection against demand fluctuations and upward price changes. The supply cost may be reduced by decreasing inventory levels; however, lack of spare parts may result in costly system down time. In order to avoid prolonged equipment down time, sufficient spare parts should be kept in inventory. Therefore, a balance has to be sought between inventory cost and customer service (Heizer & Render, 2010:500-501). Nevertheless, spare part support is more complex than many people realize and it is often performed poorly, even by world-class companies (DeCastro, 2006:115).

An aircraft consist of multiple items; both consumable and repairable. Consumable item are discarded after their useful period. Repairable items are repaired and returned to service rather than discarded. Aviation assets tend to be expensive and it is less expensive to repair than to replace. Repairable items are common in the military and commercial sectors. Repairable item examples are aircraft and aircraft components, transportation equipment, and electronics. Repairable item inventories are considerably more complicated than traditional consumable inventories. Even though some level of success can be achieved by traditional inventories, it might not be the optimal solution. The typical problem of the repairable inventory systems is concerned with the optimal stocking of spare parts for aircraft at bases and a central repair depot. The bases are capable of repairing some broken parts, but not all, while the repair depot serves all of the bases. In order to maximize the aircraft availability, repairable inventory systems strive to minimize spare part shortages, subject to a budget constraint (Guide Jr. & Srivastava, 1997:1-3).

Terminology

Terminology is helpful to understand repairable inventory theory. The demand for an item is considered either independent or dependent. Independent demand is the demand that must be forecasted. Dependent demand is the demand that is obtained from the demand for a higher-level item. For example, the demand for a toaster is independent and must be forecasted; while the demand for a subcomponent (used in the toaster) is derived from the demand for the toaster. The demand for an item may stay relatively constant (stationary demand) or fluctuate dramatically (dynamic demand) over time. In the military, peace time has stationary demand, while war time has dynamic demand. The stocking of spare parts can be optimized either in single-echelon or multi-echelon. Single-echelon systems optimize the spare parts for a single facility (either a base or depot), without considering the other facilities. However, multi-echelon systems optimize the spare parts for the entire logistics structure (bases and depot). Stock level of an individual repairable item can be optimized in two different ways; single-item or multi-item basis. Single-item systems determine the optimal stocking levels on an item-by-item basis; while multi-item systems determine the optimal stocking levels on a system-wide basis. Recognition of embedded parts hierarchy is called indenture support (Johnson, 2010:Lecture 12).

Unique Aspects of Maintenance Inventories

Maintenance inventories are used to assist maintenance crews in keeping the system in operational condition. These inventories are not final products to be sold to a customer and governed by different policies. The demand is dictated by how the system is used and how it is maintained. Furthermore, maintenance actions can be postponed or even avoided according to operational conditions. Most items are repairable in these inventories; however, some broken parts can be discarded like consumables as well. Failure times can be predicted with item reliability information, which is generally not available because equipment monitoring systems are not installed for all items. Aircraft have complex structures with cross system dependencies. Part failures often caused by other systems. Complex system structures make it difficult to deal with these part failures, particularly if the cross system dependencies are not well known. Demand may be met through cannibalism of other spare parts or systems. Being out of a part generally affects the quality of the system and increases risk to personnel. Such risk are not easy to calculate, especially in the military aircraft these risks may be fatal. Spare parts are used to maintain systems that have a long life cycle. Such systems are faced with severe obsolescence and it is difficult to determine how many spare parts to stock for an obsolete system. As the aviation assets get more expensive every year, once-consumable products become repairable. This increases the demand for maintenance and maintenance inventories. More spare parts are stocked than complete units, and repair is preferred to replacement (Kennedy, 2002:201-202). Maintenance inventories are also affected by environmental issues, such as operation tempo, policy changes, vanishing vendors, and number of deployments. This makes maintenance inventories harder to manage (Oliver and others, 2001:32).

Logistics Pipeline

The repairable asset pipeline is a system of supply, repair, and transportation services that together form a distribution network for repairable spare parts. All pipeline models share common attributes: flow rate into the system, flow time through the system, and volume. When a repairable part fails, it becomes unserviceable and it goes through the logistics pipeline to be repaired. Only the spare parts that are on the shelf can be used by maintenance crews; however, the parts that are in the logistics pipeline are not on the shelf to be used. It can be assured that there is at least one serviceable spare part on the shelf by accurately calculating the quantity of assets required to fill the pipeline (Johnson, 2010:Lecture 12).

Palm's Theorem

Palm's theorem is used to calculate the quantity of assets required to fill the logistics pipeline. According to the Palm's theorem, if demand for a spare part is a Poisson process with rate λ and the repair time for unserviceable parts is an arbitrary probability distribution with mean τ, then the steady-state (long term average) probability distribution for the number of items in repair has a Poisson distribution with mean $\lambda * \tau$. The Palm's theorem allows us to calculate the probability of having a specific number of assets in the logistics pipeline (Johnson, 2010:Lecture 14).

Inventory Performance Measures

Three different metrics can measure the performance of an inventory system: ready rate, expected fill rate, and expected backorders (Johnson, 2010:Lecture 12).

Ready Rate

The Ready Rate (RR) is defined as the probability that a serviceable spare part exists on the shelf. It shows the maximum number of demands that the inventory can experience and still have at least one serviceable spare part ready to use.

$$Ready\ Rate = \sum_{x=0}^{S-1} \Pr(X = x) \tag{5}$$

In Equation 5, the inventory stock level is S and the number of assets in the pipeline is X. The ready rate is a useful managerial metric; however it is not related to the system performance, or availability. Having a ready rate of 80% does not guaranty an aircraft availability of 80%.

Expected Fill Rate

A backorder is created when a malfunction occurs and there is no serviceable spare part available for maintenance crews to use. The Expected Fill Rate (EFR) is defined as the probability that no back-orders will occur. It shows the maximum number of demands that can occur before creating a back-order.

$$Expected\ Fill\ Rate = \sum_{x=0}^{S} \Pr(X = x) \tag{6}$$

In Equation 6, the inventory stock level is S and the number of assets in the pipeline is X. EFR will always be equal to or greater than the ready rate.

Expected Backorders

The Expected Backorders (EBO) metric is defined as the long term average number of backorders experienced given a particular inventory stock level and average demand.

$$Expected\ Backorders = \sum_{x=S+1}^{\infty} \left((x - S) * \Pr(X = x)\right) \tag{7}$$

In the Equation 7, the inventory stock level is S and the number of assets in the pipeline is X. It is harder for inventory managers to understand compared to the ready rate and expected fill rate. A backorder means a missing part in an aircraft and thus creates system down time; minimizing backorders then is equivalent to maximizing aircraft availability. Many inventory managers tend to favor other inventory performance measures, because they are easy to understand and more meaningful for them (DeCastro, 2006:116).

Item vs. System Approach

Traditional inventory models focus on individual items with the goal of minimizing cost. Stock levels are determined on an item-by-item basis, without considering their effects on the system performance. The item approach performance is measured by fill rate, the percentage of demands satisfied off-the shelf. As mentioned before, the ready rate and expected fill rate metrics are useful managerial metrics. These metrics are easy to understand; however, they are not directly related to the system performance, or aircraft availability. Having a ready rate of 80% all across the inventory, does not guaranty an aircraft availability of 80%. Rather, it means that the inventory will satisfy 80% of overall item requests from off-the-shelf stock. Inventory managers try to maintain sufficient levels of inventory to achieve specified fill rate. Relatively inexpensive items will have fill rates higher than 80% and expensive items will have lower than 80%, averaging at 80%. Under the item approach, the system availability is the result of many item based decisions. The item approach results in inefficient spare part support and uncontrolled system performance (Johnson, 2010:Lecture 12).

However, spare part support is used to assist a maintenance crew in keeping the system in operational condition. Inventory decisions cannot be made independent from aircraft availability. Every spare part has a different bearing on the system performance, due to its importance, price, supply source, failure and repair characteristics, and many other factors (DeCastro, 2006:115). Therefore, inventory stock level of individual spare parts should be set to optimize the overall system performance. Imagine there are two spare parts with exactly the same demand and repair characteristics. One costs $200 and the other $4,000. It is obvious that in order to achieve the highest availability, one should buy relatively more of the inexpensive part and fewer of the expensive one according to their prices. Effective methods should be implemented to ensure the greatest marginal improvement in system availability per monetary unit. The item approach results in inefficient spare part support and uncontrolled system performance. This can be seen in Figure 5. The system approach, however, generates an optimal cost vs. availability curve, which then can be used to obtain the same level of performance with less inventory investment (Johnson, 2010:Lecture 12).

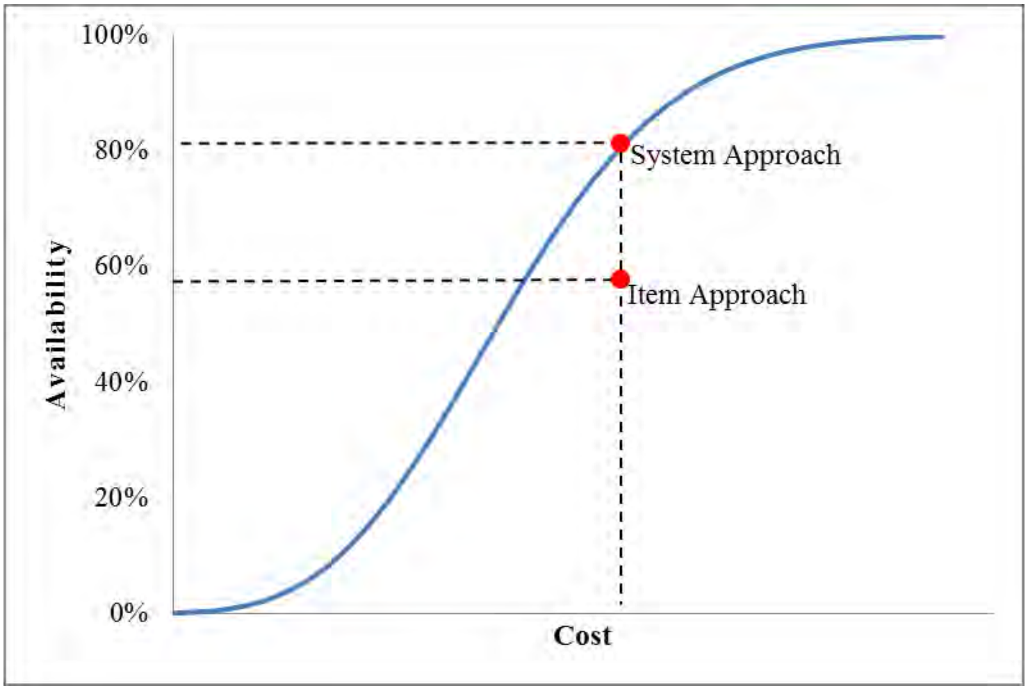


Figure 5: Item vs. System Approach

The system approach is widely used in air forces. For example Readiness-Based Leveling (RBL) system of the United States Air Force uses the system approach to allocate scarce resources (Johnson, 2010:Lecture 20). The RBL is considered as the cornerstone for setting recoverable parts levels in the supply system (Fulk, 1999:3).

Logistics Management Institute (LMI) compared the two approaches using F-16C Fighting Falcon data from the United States Air Force (USAF). Results are shown in Table 2. The system approach provided the same aircraft availability with a 40% budget savings over the item approach. Alternatively, the system approach increased availability by 30% for the same cost incurred under the item approach (Slay and others, 1996:1-5).

Table 2: Item vs. System Approach

Performance Measures	Item Approach	System Approach	
		Minimizing Cost	Maximizing Availability
Availability	54%	54%	84%
Cost ($ Millions)	$14.5	$8.6	$14.5

Repairable Inventory Systems Taxonomy

Repairable inventory systems are more complex than consumable inventory systems. Because of its complexity, many authors have chosen to focus their efforts on the single-echelon models to remove some of the complexity. Multi-echelon models, however, addresses this necessary complexity of supply systems. The problem is the determination of spare part levels at each base such that a desired level of service level is obtained, given a budget constraint, repair rates, and repair and transportation times (Guide Jr. & Srivastava, 1997:5-8).

Many repairable inventory systems are based on Sherbrooke's study in 1968, Multi-Echelon Technique for Recoverable Item Control (METRIC) (Sherbrooke, 1968). METRIC takes a system view for setting repairable spare part levels and allocating these parts so as to obtain some desired level of service. METRIC uses backorder minimization to achieve the desired service level (Silver and others, 1998:505-506). METRIC model assumes multi-echelon and multi-item system; however, it is limited to single-indenture and stationary demand. Shortcomings of METRIC are addressed by several METRIC-based models, such as Mod-METRIC, Dyna-METRIC, and Vari-METRIC. For example, Dyna-METRIC deals with the problems of multiple indenture and variance of logistic pipeline inventories (Guide Jr. & Srivastava, 1997:8-12). Taxonomy of repairable inventory systems is given in Figure 6.

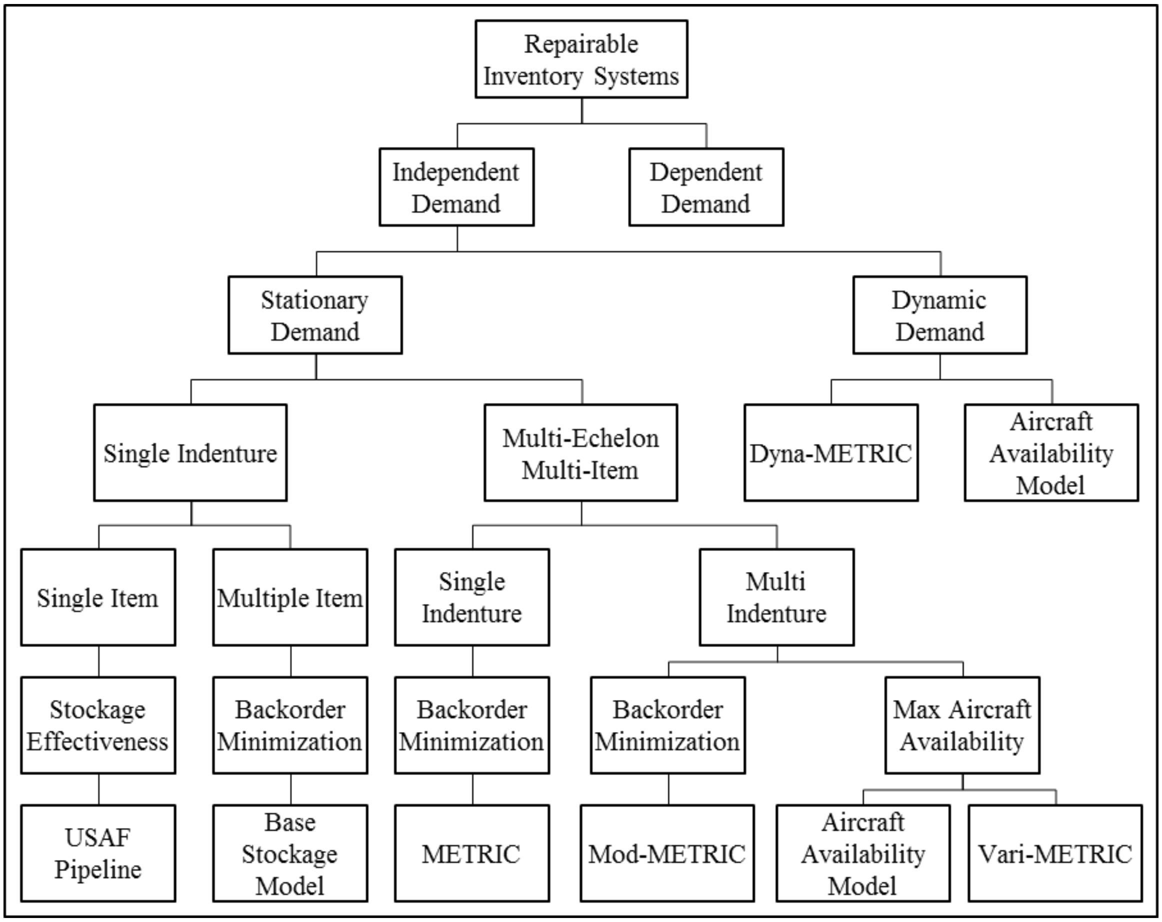


Figure 6: Repairable Inventory System Taxonomy (Johnson, 2010:Lecture 12)

Aircraft Sustainability Model (ASM) Overview

The Aircraft Sustainability Model (ASM) is a tool created by Logistics Management Institute (LMI) for the United States Air Force. ASM is a mathematical statistical model, which uses the system approach to compute optimal spares mixes to support a wide range of possible operating scenarios. Traditional inventory systems use supply-oriented performance measures, such as ready rate or expected fill rate. ASM, on the other hand, computes the optimal spare mixes based explicitly on desired system readiness, such as aircraft availability (Slay and others, 1996:iii-iv).

> Military planners must calculate spares requirements to support weapon-system readiness over a wide range of possible situations. Using the operational parameters of those situations and the characteristics of the weapon system's components - including projected failure rates, repair times, and procurement costs - the Aircraft Sustainability Model (ASM) computes cost-effective spares mixes to minimize waiting time for spare parts (Slay and others, 1996:1-1).

ASM uses aircraft availability as the measure of inventory performance. Aircraft availability is defined as the percentage of the fleet that is not grounded for lack of spare parts. Spare parts are selected by using a marginal analysis technique that selects items on the basis of their contribution to aircraft availability per unit cost. ASM guaranties cost-effective spare part mixes and produces an optimal cost vs. availability curve. ASM provides evaluation of existing spare part inventory. The scope of ASM is a single weapon system. ASM requires certain information to be available, such as demands (failures) per flying hour, repair and transportation times, operation tempo, and daily flying-hour profile (Slay and others, 1996:1-1).

In order to produce the optimal cost vs. availability curve, ASM considers a number of other factors:

Indenture: ASM has indenture support, which is the recognition of embedded parts hierarchy. First-indenture components are replaced while the aircraft sits on the flight line. These components are called Line Replaceable Units (LRUs). LRU repair involves replacing second-indenture components, which are called Shop Replaceable Units (SRUs). SRU repair involves replacing third-indenture and so on. The lack of a spare LRU, grounds the aircraft almost immediately, while the lack of a spare SRU affects availability indirectly through LRU availability. ASM produces the optimal balance between procuring LRU and SRU spares.

Essentiality: The aircraft availability is mainly affected by high-cost, high-indenture items, such as repairable LRUs and SRUs. ASM focuses on the essential items.

Cannibalization: Spare part shortages can be consolidated onto a single aircraft or component. This is called cannibalization. Cannibalization greatly improves aircraft availability without increasing procurement costs. Cannibalization increases the maintenance actions.

Flexible Scenarios: ASM supports steady state (peace time) and/or dynamic (war time) scenarios. ASM can deal with many different operational scenarios. Operation tempo can be changed during the course of the scenario. Repair and supply may be suspended for a period. Cannibalization status (allowed, not allowed) can be changed.

Multi-Echelon Supply Structure: In multi-echelon supply systems, spare parts can be stored at several operating bases and also at a central depot. ASM allocates the spare parts optimally between the bases and the depot to maximize aircraft availability.

Component Stock Considerations: ASM accepts user-specified spare part levels that are already in the inventory (Slay and others, 1996:1-2).

A typical implementation of ASM results in up to 25% saving in the inventory investment, compared to the item approach. ASM is capable of calculating optimal spare levels for both repairable and consumable items. ASM optimizes the spare part support by using the system approach. Spares are selected and put into a shopping list ordered by their benefit-to-cost ratio. The shopping list method ensures the greatest marginal improvement in aircraft availability per monetary unit (Slay and others, 1996:2-16).

ASM is typically used for four types of spares analyses: Initial Provisioning, Replenishment, Deployment Spares, and Evaluation.

Initial Provisioning: ASM can estimate the spare part requirements of a single aircraft type for a specific period (months, quarters, years). Given aircraft delivery schedule by period, ASM provides cost of deliveries and year by year budgets. The United States Air Force (USAF) used ASM in the provisioning phase of F-22 Raptor for multi-year deliveries and budgets.

Replenishment: Given the existing assets, ASM can estimate the spare part requirements in the coming year. This capability is similar to initial provisioning.

Deployment Spares: Deployment locations are usually far from supply centers. ASM can estimate the spare part requirements for the deployment locations with dynamic aircraft usage and cannibalization.

Evaluation: ASM can evaluate the existing spare part mix over a dynamic period for aircraft availability.

Summary

In this chapter, a literature review on aircraft availability was provided to assess the feasibility of a research on proper spare part selection for the A400M aircraft. The chapter began by defining the aircraft availability and affecting factors. It was found that logistic operations have significant influence on the aircraft availability and sufficient spare part support is essential to achieve desired availability levels. The chapter moved on to a brief review of inventory theories. Next it addressed unique aspects of maintenance inventories and common inventory performance measures. It was shown that traditional item approach results in inefficient spare part support and uncontrolled system performance. The system approach was found more suitable than item approach for this study, because it can provide the same aircraft availability with up to 40% budget savings. Finally the chapter concluded with an overview of the Aircraft Sustainability Model (ASM). ASM provides the optimal cost vs. availability curve and it is widely used for provisioning, replenishment, and deployment spares decisions.

III. Methodology

Chapter Overview

The goal of this chapter is to describe the methodology used to determine proper spare part support for the A400M aircraft. The chapter begins by providing the purpose of this study and investigative questions. Next, it presents the assumptions and data, which this research is founded on. An overview of the Aircraft Sustainability Model (ASM) is provided along with its processing steps. The chapter continues with a conceptual example to show the steps of ASM methodology. Finally, the chapter concludes with the research design and how the research is conducted.

Research Question

The A400M comes with technological improvements and increased component reliability. It also applies modern maintenance and support concepts to improve aircraft availability and reduce life cycle cost (Heuninckx, 2011:1). The Turkish Air Force's total orders of 10 aircraft are scheduled to be delivered between 2013 and 2018. The A400M is expected to extend the Turkish Air Force's ability to transport personnel, equipment, and supplies onto theaters of operation. In order to be successful in this goal, high aircraft availability of the A400M has to be achieved by sufficient spare part support. The necessary spare parts should be obtained and stored at repair facilities prior to the aircraft deliveries. However, spare parts are expensive to procure, store and manage. A balance has to be sought between aircraft availability of the A400M and the cost of spare parts. The Turkish Air Force initially aims to achieve 80% aircraft availability for the A400M. Important insights and tradeoff opportunities can be gained by researching the characteristics of the A400M. Hence, this research seeks to answer the following question:

Which spare parts should the Turkish Air Force procure for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts?

Investigative Questions

Answering the research question requires several other investigative questions to be answered.

1. What is the cost vs. availability curve of the A400M fleet with the Turkish Air Force's maintenance structure?
2. What is the optimum aircraft availability of the A400M? Is the aircraft availability goal of 80% viable?
3. How does each aircraft delivery affect the supply support cost and the cost vs. availability curve?
4. What is the supply cost distribution among the A400M subsystems?

Data and Assumptions

As mentioned in the literature review chapter, spare part support is more complex than many people realize and it is often performed poorly, even by world-class companies (DeCastro, 2006:115). Determining the essential spare support requires detailed information about operation environment, maintenance structure, and historical reliability data. However, there is no historical data yet available for the A400M aircraft. This study is conduct by using Airbus's reliability estimates and the Turkish Air Force's supply structure. The A400M Procurement Project Group sponsored this research and provided all necessary data. The group provided the most recent material list of the A400M aircraft, reliability estimates, and information about A400M support structure.

The data provided by the A400M Procurement Project Group consists of details about 300 LRUs from 5 different systems of the aircraft. Information is given in an Excel spreadsheet, which contains item name, cost, quantity per aircraft, and other related item information. The spreadsheet is given in OPUS10 format, which is another program for spare part calculations. The data has been manipulated, in order to protect the Turkish Air Force's best interest.

As mentioned in the literature review chapter, the aircraft availability depends on many factors, such as maintenance work force, ground equipment, training, operation environment and more. However, this research is established on a logistician perspective. The research is founded on the key assumption that the aircraft availability is determined only by the spare part support and supply structure. This key assumption gives us the ability to perform relevant inventory management techniques to gain insights of the characteristic of the A400M. Reliability engineering has a field of its own and reliability of the A400M is not considered in this study.

The A400M program is currently in the initial logistics provisioning phase. The Turkish Air Force is gathering the necessary support products, such as technical documentation, spare parts, ground equipment, training and training aids. The maintainability of the A400M will be affected by this adoption period following a learning curve. Local production of the spare parts, interaction with other aircraft platforms, changes in the mission requirements and the technology transfer will affect the maintainability and even the reliability of the A400M. The maintenance capabilities will change over time notably. In order to capture the effects of the spare part support, the reliability and the maintainability of the A400M were assumed constant.

Complex structure of supply systems and the lack of publicly available data require further assumptions to be made. Data provided by the A400M Procurement Project Group is supported with the following assumptions. The planning horizon is assumed to be 5 years. Table 3 shows the delivery quantity and quantity in service over the course of delivery period.

Table 3: The A400M Delivery Quantity and Quantity in Service

Year	Delivery Quantity	Quantity in Service
2013	1	1
2014	2	3
2015	4	7
2016	2	9
2017	1	10

There are many factors related to the total mission capable hours, the main driver of aircraft availability. These factors can be into five categories: aircraft reliability and maintainability, personnel, environment, aircraft operations, logistics operations, and of course funding (Oliver and others, 2001:32). In order to isolate the effects of logistics operations, other factors are held constant. Therefore, it is assumed that the A400 aircraft will be stationed at a single base and the aircraft utilization will be stable at 650 FH per year per aircraft, in order to represent the peace time operations. It is also assumed that initially the Turkish Air Force will not have any repair capability and this service will be provided by Airbus entirely (with the order and shipment time of 8 days).

Aircraft Sustainability Model

The Aircraft Sustainability Model (ASM) is a mathematical statistical model, which computes optimal spares mixes to support a wide range of possible operating scenarios. It is created by Logistics Management Institute (LMI) for the United Sates Air

Force. Despite traditional inventory systems, ASM computes the optimal spare mixes based explicitly on desired system readiness, such as aircraft availability (Slay and others, 1996:iii-iv).

ASM determines the optimal spare mixes by using a marginal analysis technique that selects items on the basis of their contribution to aircraft availability per unit cost (Slay and others, 1996:1-1). A typical implementation of ASM results in up to 25% saving in the inventory investment. ASM is capable of calculating optimal spare levels for both repairable and consumable items (Slay and others, 1996:2-16). In this study, ASM is chosen to determine the essential spare part support for the A400M aircraft.

Spares are selected and put into a shopping list ordered by their benefit-to-cost ratio. The shopping list method ensures the greatest marginal improvement in aircraft availability per monetary unit (Slay and others, 1996:2-16). ASM guaranties cost-effective spare part mixes and produces an optimal cost vs. availability curve. ASM requires certain information to be available, such as demands (failures) per flying hour, repair and transportation times, operation tempo, and daily flying-hour profile (Slay and others, 1996:1-1).

Processing Overview

ASM uses item characteristics, scenario data, and supply structure information to estimate the optimal spare mix that is required to obtain a system (not item) availability goal. This spare mix is called optimal in the sense that no other mix can provide a higher availability for the same cost, or the same availability for less cost (with respect to assumptions and data). In order to create the optimal spare mix, ASM computes an item level (the number of units that should be in the supply system) for each item. This item level is obtained by combining the number of assets that are serviceable and on the shelf, in repair, in transit, or on order from suppliers. Steps for calculating item levels are listed below and shown in Figure 7:

1. Daily demand rates are calculated, given operating hour scenario and item data.

2. Demand rates and resupply times are used to estimate item pipelines.

3. Pipeline estimates and assets are used to estimate item backorders.

4. Backorders are distributed over the fleet to estimate system availability.

5. An iterative process is used to build item levels. The process starts with a level of zero for each item. Then the most beneficial item is found and its level is increased by one. The most beneficial item is defined as the item where increasing the level by one yields the largest increase in system availability per unit cost. The process continues finding the most beneficial item and increasing its target by 1 until either it meets the availability goal or reaches the budget constraint (Kline and others, 2001:1-7 to 1-10).

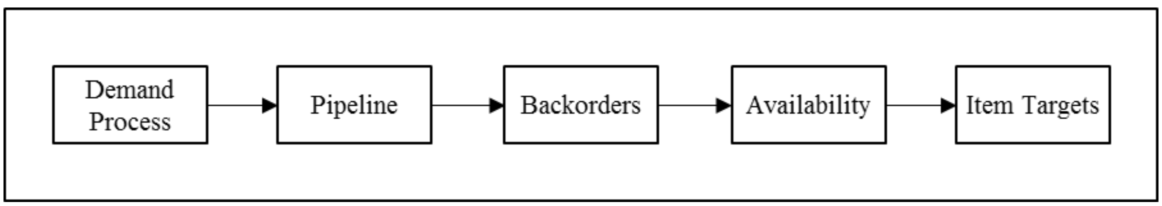


Figure 7: Model Processing Overview

Steps in Methodology

A conceptual example is presented in this section to illustrate calculation of aircraft availability. The example is taken from ASM User Manual (Kline and others, 2001). The example starts with a deterministic one-item system, in order to show how to find the optimal spare level in the simplest case. In the next step, demand randomness is introduced because demand is really both variable and uncertain. Later, the example introduces multiple items and optimal spares mixes. Finally, the example advances into multiple echelons and multiple indentures, in order to be more realistic.

Deterministic Demand

Deterministic and constant demand is too good to be true; however, it is necessary to start simple, in order to understand calculation steps of aircraft availability. In this section, demand is deterministic and constant, and the resupply time is also constant. Later, these assumptions will be changed to obtain a better grasp of reality.

Suppose that there is a fleet of eight aircraft, and the goal is to obtain 100% aircraft availability (no grounded aircraft). Each aircraft has one unit of Part A installed. The fleet's operation conditions results in a constant failure rate of one unit per day for Part A. In order to restore the aircraft to flyable condition, the maintenance crew replaces the failed part if it is in stock, or files a request from the supply system. It always takes 3 days for the supply system to get that unit of Part A.

Assume today is the first day of flight, all aircraft are mission capable, and there is no spare of Part A present. When the day ends, one aircraft becomes grounded because of a failed Part A, and the maintenance crews files a request. It always takes 3 days for the supply system to get that unit of Part A. Another aircraft becomes grounded on the second day, and another one on the third day. The following days are different from the first three. For example, on the fourth day, another unit of Part A fails; however, no aircraft becomes grounded because the supply system gets one unit of Part A that was ordered on the first day. The same process occurs on the following days. Number of grounded aircraft reaches a steady state of three grounded aircraft.

In steady state, there are three units of Part A in the logistics pipeline (in repair, in transit, or on order from suppliers). Equation 8 shows the calculation of aircraft availability. Since each aircraft in the fleet has one unit of Part A installed, there are three grounded aircraft in steady state. 37.5% (3/8) of the fleet is grounded due to lack of spare parts. In another words, aircraft availability is 62.5% (5/8). When the item level of Part A is increased from zero to one, it allows another plane to be restored to flyable condition. An item level of one decreases the total backorders to two, and increases aircraft availability to 75%. When the item level is increased to two units, it yields aircraft availability of 87.5%. An item level of three yields 100%. Note that the optimal target of three is equal to the number of assets in the logistics pipeline.

$$Availability = 1 - \frac{Grounded\ Aircraft}{Total\ Aircraft} \tag{8}$$

Random Demand

In this section, demand randomness is introduced into the example because in real world, demand is both variable and uncertain. Demand is assumed to be random with the average daily rate of one unit. This means that Part A can experience more or less than one demand per day; however, the average demand is one unit per day in the long run. Since the daily demand is random, the pipeline of three units becomes the average number of units in the logistics pipeline. The total number of units in the logistics pipeline can be calculated via expected (average) backorders (EBOs).

Given demand follows a Poisson distribution with a mean of λ, the probability that exactly n units are in the logistics pipeline can be calculated as in Equation 9. Figure 8 shows both Cumulative Distribution Function (CDF) and Probability Density Function (PDF) of Poisson distribution for a pipeline of three items (λ=3). For example, the probability that exactly four units are in the logistics pipeline is 17%.

$$PDF(n) = \frac{e^{-\lambda} * \lambda^n}{n!}, n = 0,1,2,3 \ldots \tag{9}$$

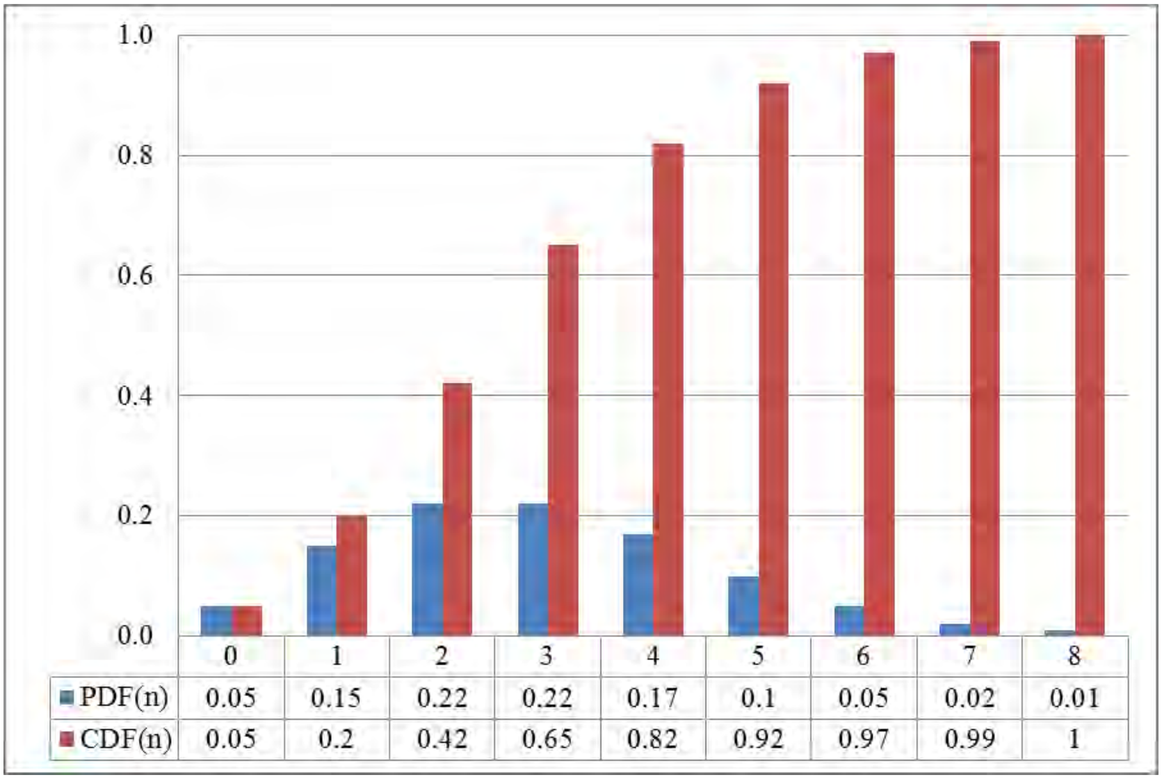
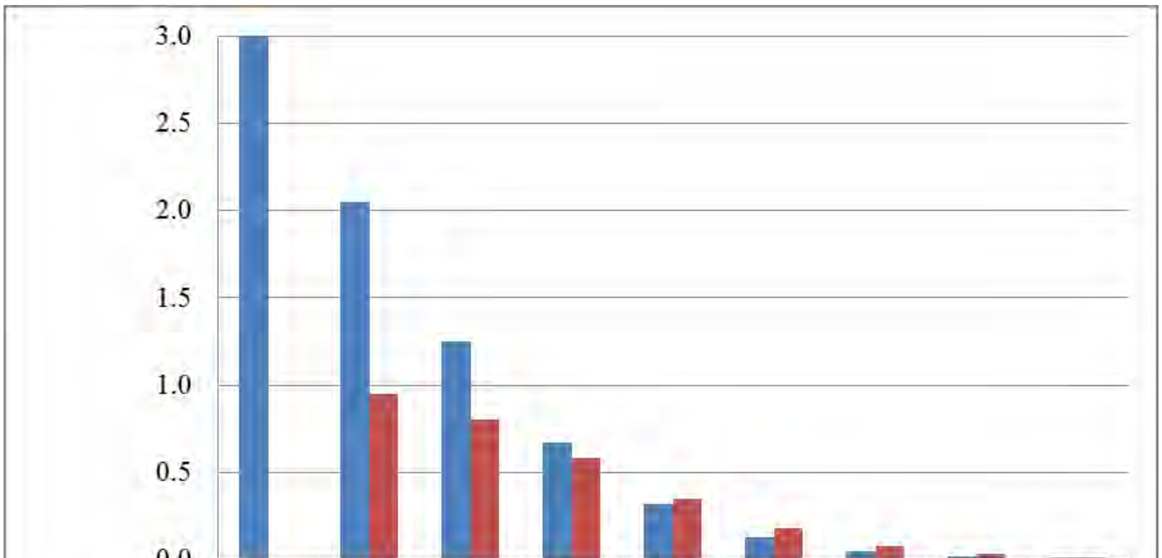


Figure 8: Poisson Distribution (PDF and CDF) for a Pipeline of 3 Units

The distribution of the number of units in the logistics pipeline is useful; however, all alone it does not yield any information about aircraft availability. In order to relate the average daily demand rate to aircraft availability, expected (average) number of backorders (EBOs) must be used. Expected backorders then will be distributed over the fleet to calculate expected aircraft availability. Given s signifies the number of spares; the expected backorders can be calculated as in Equation 10. For example, where there are no spares available, the expected backorders simply reduce to three, the average number of assets in the logistics pipeline.

$$EBO(s) = \sum_{n>s} (n - s) PDF(n) \tag{10}$$

Expected backorder equation shows that the expected number of backorders is not linearly related to the number of spares, as it was under deterministic demand. Figure 9 shows how the expected number of backorders changes with number of spare parts. Figure 9 also shows the marginal change (benefit) in the expected backorders per cost with each spare part increase. It is assumed that Part A costs \$1,000. Note that calculations are made for a pipeline of three units.



	0	1	2	3	4	5	6	7	8
EBOs	3.00	2.05	1.25	0.67	0.32	0.13	0.05	0.02	0.01
Benefit/\$K		0.95	0.80	0.58	0.35	0.18	0.08	0.03	0.01

Figure 9: Number of Spares vs. Marginal Benefit per Cost

One backorder grounds approximately one aircraft, assuming that there is no part cannibalization. Therefore, aircraft availability can be easily calculated via expected backorder distribution. For example, having no spare parts causes an expected backorder of three units, and yields an aircraft availability of 62.5%. The first spare part increases the availability up to 74.4%, while the second and the third yield 84.4% and 91.6% consecutively. The cost vs. availability curve is created by combining the aircraft availability and number of spares (cost) information. Figure 10 shows the cost vs. availability curve for a pipeline of 3 units.

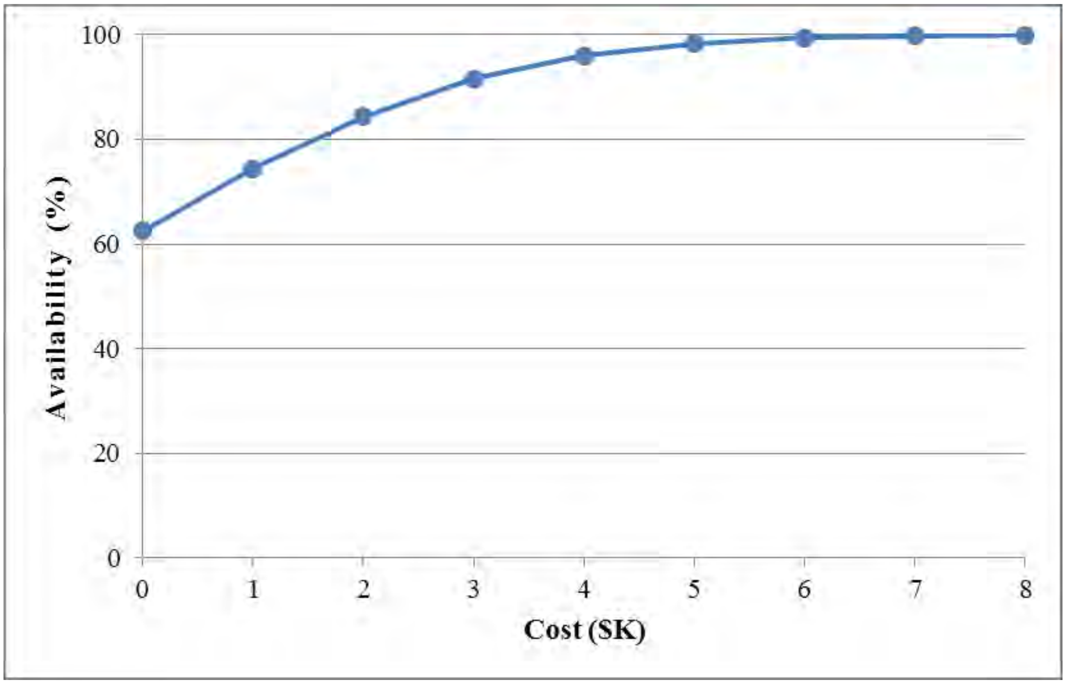


Figure 10: The Cost vs. Availability Curve for a Pipeline of 3 Units

Multiple Items

Aircraft are made out of multiple parts; each part has a different bearing on aircraft availability, due to its price, failure and repair characteristics, and etc. It is important to capture multiple-item aspect of the maintenance inventories. ASM models each item's availability independently, and computes an availability level for each item. Then, aircraft availability is calculated as the product of all item availabilities. Given EBO_l is the total expected backorder for Part L, and the number of systems (#Systems): Equation 11 shows the calculation of aircraft availability.

$$Availability = \prod_{l} \left(1 - \frac{EBO_l}{\#Systems}\right) \quad (11)$$

ASM uses marginal analysis to determine the optimal spare mix. ASM builds the shopping list one item at a time, using benefit/cost ratios. Every item starts with an item level of zero. Every item starts with an item level of zero units. Then, ASM selects the item with the largest benefit-to-cost ratio, and increases that item's level by one. ASM repeats this iterative process until either it meets the availability goal or reaches the budget constraint. Detailed information is provided in ASM User Manual (Kline and others, 2001).

Multiple Echelons and Multiple Indentures

In a typical supply system with multiple echelons, spare parts can be stored at several operating bases and also at a central depot. At this level, ASM introduces another echelon of pipeline to represent the depot operations. A depot spare reduces the total EBOs by reducing the depot-pipeline for all the bases, while a spare at a particular base will only reduce EBOs at that base (but often by a large amount). Every time ASM increases an item level by one, it considers each possible depot/base combination of spares and picks the combination that yields the lowest system EBOs. ASM allocates the spare parts optimally between the bases and the depot to maximize aircraft availability, while minimizing inventory cost.

Multiple indenture support is the recognition of embedded parts hierarchy. LRUs are replaced while the aircraft sits on the flight line. LRU repair involves replacing SRUs. SRU repair involves replacing third-indenture spare parts and so on. The lack of a spare LRU, grounds the aircraft almost immediately, while the lack of a spare SRU affects availability indirectly through the LRU pipelines. ASM computes an awaiting parts pipeline from the SRU EBOs to capture the effects of SRU spares. ASM performs cross tradeoffs at multiple indentures, in order to obtain the optimal balance between procuring LRU and SRU spares.

Research Design

In order to answer the research question, ASM is chosen to determine the essential spare part support for the A400M aircraft. The Turkish Air Force is procuring 10 A400M aircraft, which will be delivered over the course of 5 years, starting from 2013. The delivery schedule and the number of aircraft in service over this period were given in Table 3 at page 30. In general, this study develops an ASM model for the A400M aircraft with various fleet sizes, and compares the results, in order to determine the optimal spare part mix.

Initially, the Turkish Air Force will not have any repair capability and this service will be provided by Airbus entirely. Every time a failure occurs, maintenance crews will remove the malfunctioning part and replace it with a spare part if there is a serviceable part available at base. Otherwise, the malfunctioning part will be sent to Airbus facilities for repair process. Figure 11 shows the Turkish Air Force's maintenance structure for the A400M aircraft. Since the deployment base has no repair capability, all malfunctioning parts are sent to Airbus facilities. In this setup, one might think that using a single echelon model would be appropriate; however, a multi-echelon model enables further research to be conducted with minimum effort.

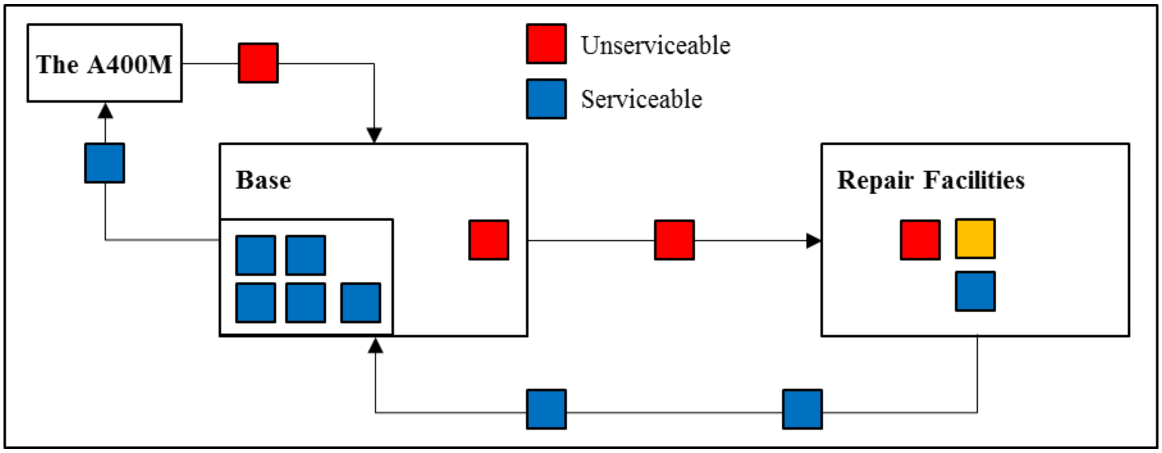


Figure 11: The Supply Structure

Using ASM

An ASM model consists of three fundamental components: baseline kit, scenario, and model parameters. The baseline kit component includes the breakdown material structure of aircraft along with item information, such as failure rate, indenture level, repair time, and quantity per aircraft. The scenario component includes number of bases, flying hours per day, and fleet size. The model parameters component includes asset projection type, availability/budget goal, and cannibalization status.

Baseline Kit

The baseline kit component includes the breakdown material structure of aircraft along with item information, such as failure rate, indenture level, repair time, and quantity per aircraft. ASM can import and export in various file-types, such as Excel spreadsheet and normal text formats. Import file structure for item data is provided in ASM User Manual (Kline and others, 2001). The ASM import structure consists of 67 columns, each columns determines a certain aspect of items, such as stock number, cost, and initial asset position.

The data provided consisted of details about 300 LRUs from 5 different systems of the aircraft. The data was given in an Excel spreadsheet; however, the spreadsheet was in OPUS10 format and it was not suitable to be imported to ASM. At this point, OPUS10 help document was used to decipher the data (Systecon AB, 2010). Two formats, OPUS10 and ASM, are the result of similar approaches, yet different in terminology and measurement units. In order to use ASM, the item information was converted into ASM format. The final spreadsheet was imported into ASM, using item data import menu. A similar screen is shown in Figure 12. A subset of the final data is provided in Appendix A.

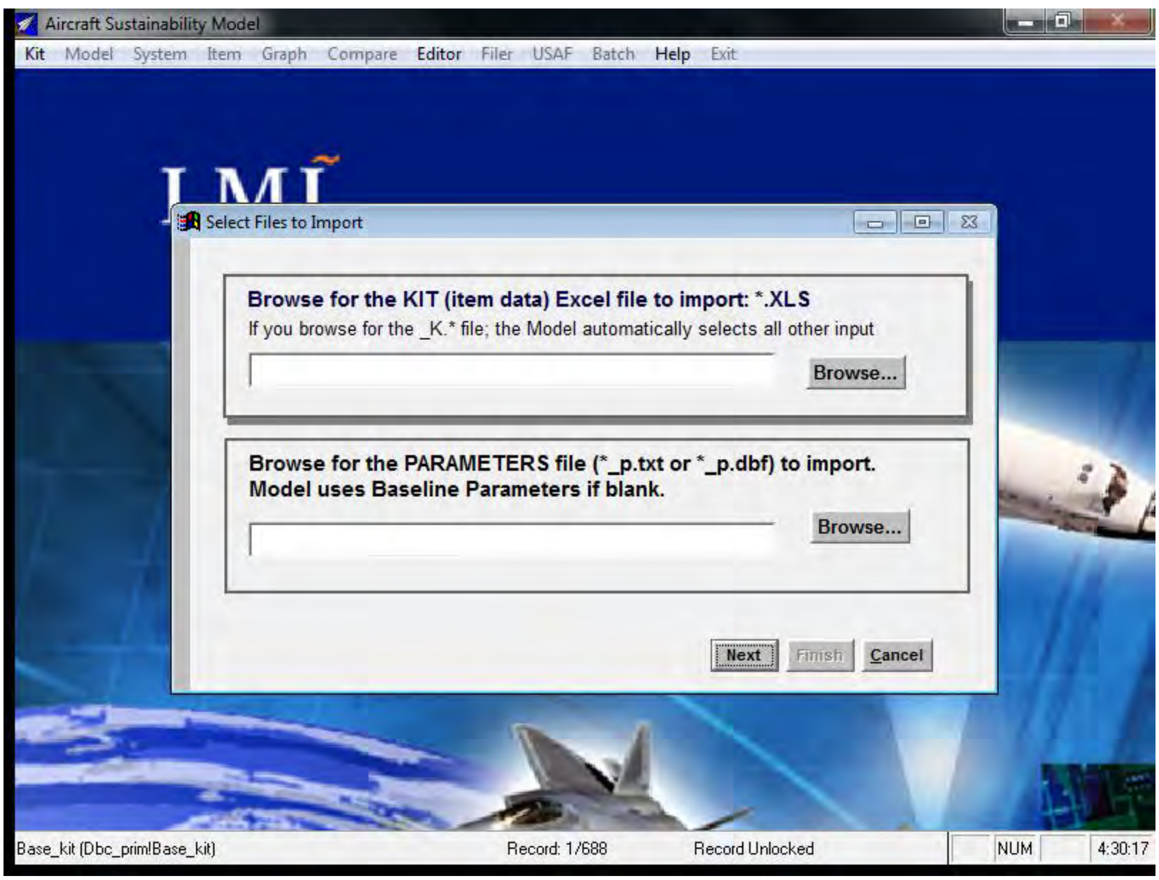


Figure 12: The Baseline Kit Import Screen

Then on the next screen, this imported baseline kit was named as "TurAF A400M" for the Turkish Air Force (TurAF) A400M study. A description and the system name (A400M) were also entered on this screen. Default ASM correction values for invalid fields were accepted as they were. Finally, this screen yielded the model parameters screen with default parameters, which were different than desired values.

Scenario

The scenario component includes number of bases, flying hours per day, and fleet size. The model parameters screen had come with default parameters, which were copied from existing baseline kit. Before making any change on these parameters, the scenario information had to be entered, because the model parameters are driven by the fleet size and analysis day values in the scenario.

On the scenario screen, data entry mode was changed to entering hours by day for one base. This action revealed a table with three fields: change (analysis) day, hours per day, and fleet size. In order to conduct a steady state analysis, change day was set to zero. Fleet size was set to 10. The last field, hours per day, requires the daily flight hours for the entire base. It is assumed that the aircraft utilization will be stable at 650 FH per year per aircraft. This assumption yields 1.8056 (650/360) FH per day per aircraft. Aircraft utilization was divided by 360 instead of 365, because ASM assumes that there are 30 days in a month. Therefore, hours per day field was set to 18.056 for 10 aircraft with 1.8056 hours per day each. Later this value was rounded to 18.06, because ASM takes two decimal points. The scenario screen is shown in Figure 13.

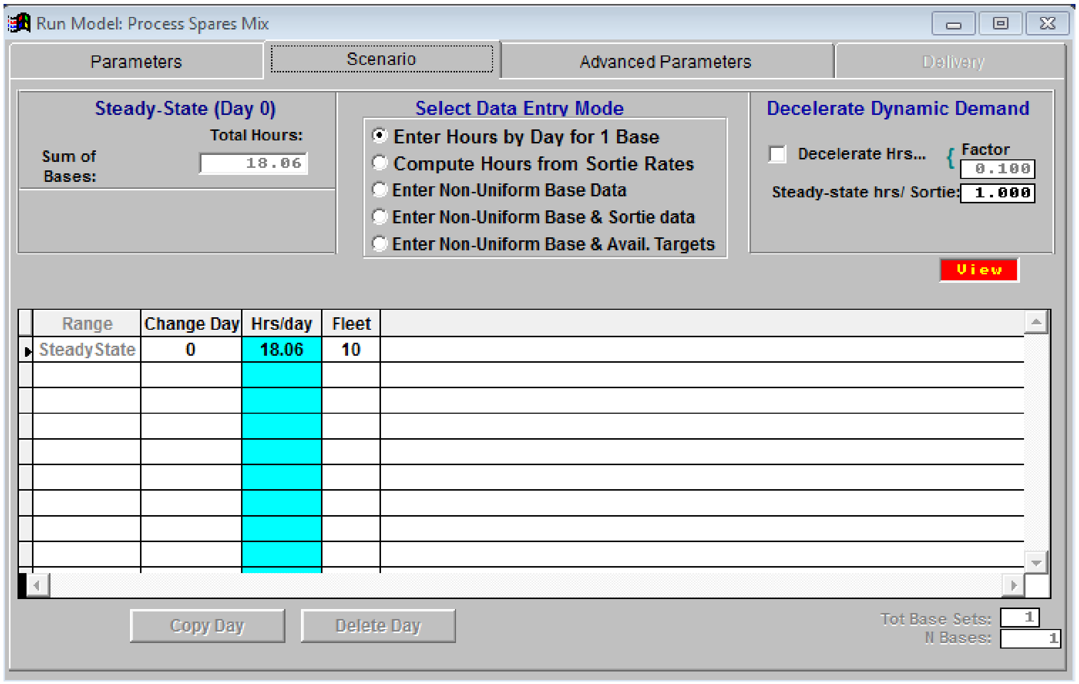


Figure 13: The Scenario Screen

Model Parameters

The model parameters component includes asset projection type, availability goal, and cannibalization status. The model parameters screen is shown in Figure 14. Asset projection type was set to analyze current conditions. As mentioned before, ASM is capable of performing calculations for both steady state (peace time) and dynamic (war time) conditions. In order to conduct a steady state analysis of the A400M aircraft; first analysis-day was set to zero and second analysis-day information was left blank. The optimal spares goal can be set as either NMCS target or availability rate. Availability goal was set to 80% and its complement, NMCS target, was set to 2 by ASM; because for a fleet size of ten, 80% availability requires 2 NMCS. Budget goal and confidence were left blank. Spare part cannibalization was set to no cannibalization for both LRUs and SRUs. At this point, ASM was ready to calculate spare part requirements.

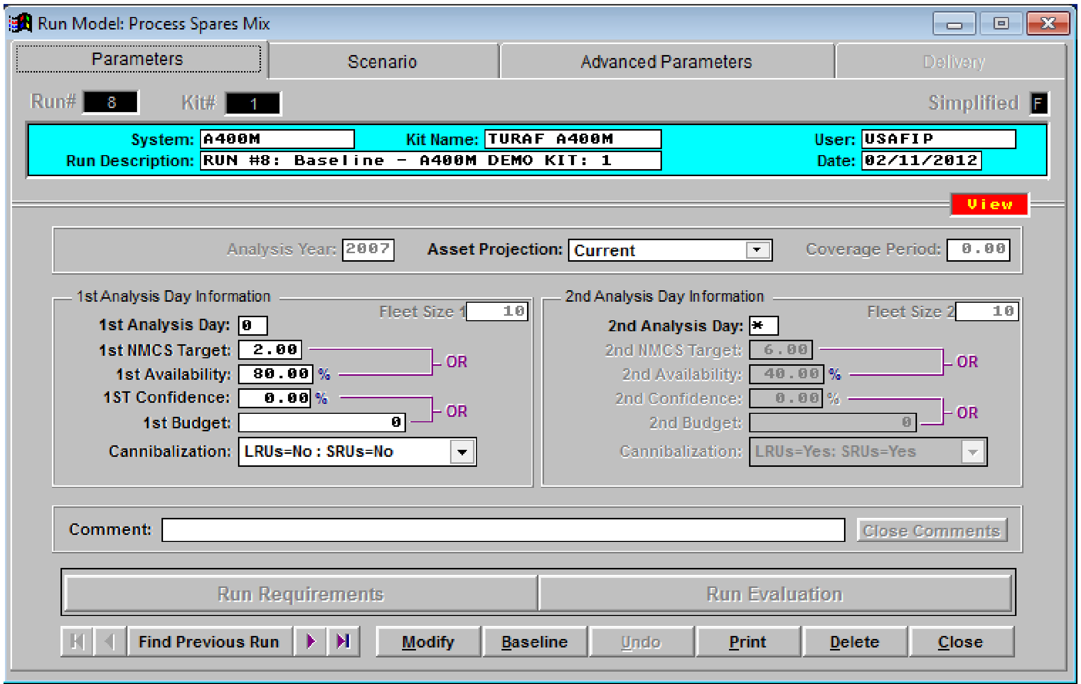


Figure 14: The Model Parameters Screen

Conducting the Experiments

In general, this study creates an ASM model for the A400M aircraft, runs this model for various fleet sizes and compares the results, in order to answer the research question. The previous section shows how the model was set up. This section explains how the experiments were conducted.

After setting up the model parameters in the previous section, ASM was ready to calculate spare part requirements. ASM calculates the optimal spare mix that is required to obtain the availability goal of 80%. ASM was run for initial calculation by clicking on "Run Requirements" button on the model parameters screen. After a short processing period, ASM showed performance summary (achieved availability and cost) of the current run for 10 aircraft with 18.06 hours per day. The performance summary screen is shown in Figure 15. Note that in this experiment, achieved aircraft availability is 80.1%.

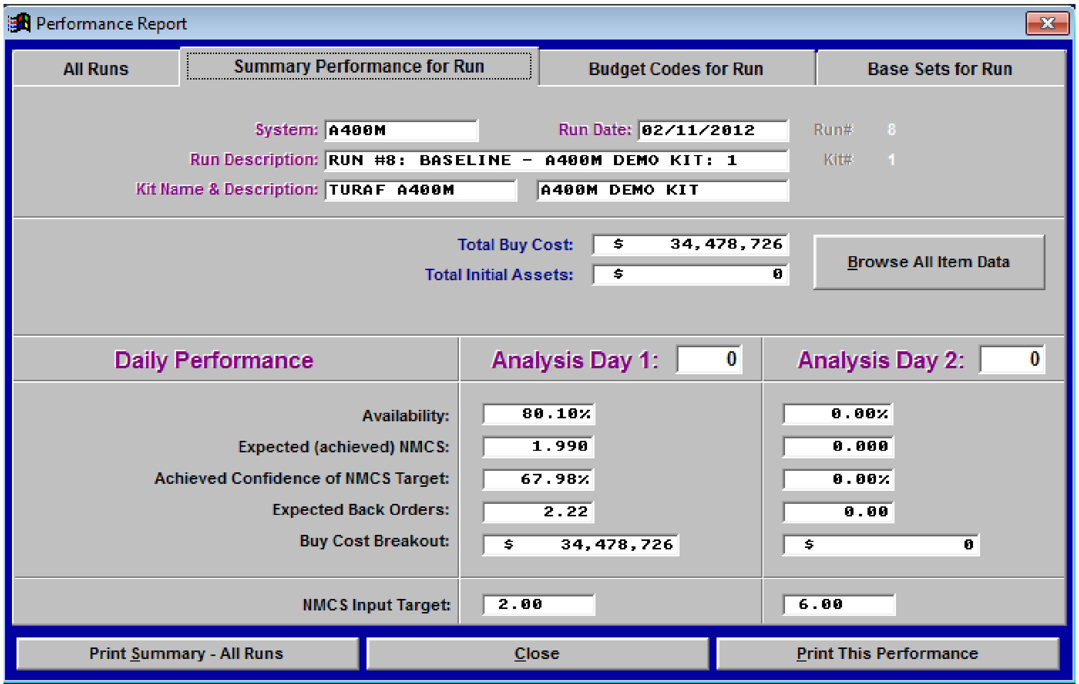


Figure 15: The Performance Summary Screen

The shopping list for the optimal spare mix is reached from the item menu. The shopping list contains offered spare mix with total procurement quantities. ASM also creates a cost vs. availability curve that can be reached from the graph menu. ASM was run with the same model for the scenarios that are shown in Table 4. The results of these experiments are provided in Chapter IV.

Table 4: The Experiment Scenarios

Scenario	Hours/Day	Fleet Size
1	18.06	10
2	16.25	9
3	12.64	7
4	5.42	3
5	1.81	1

Summary

This chapter described the methodology used to determine proper spare part support for the A400M aircraft. The chapter began by providing the purpose of this study and investigative questions. Next, it addressed the assumptions and data, which this research was founded. An overview of the ASM process was provided along with its processing steps. The chapter continued with a conceptual example to show the steps of ASM methodology. Finally, the chapter concluded with the research design, how ASM was used, and how the experiments were conducted. The results of these experiments are provided in Chapter IV.

IV. Analysis and Results

Chapter Overview

This chapter presents the results of the experiments, and analysis. The chapter begins by presenting the A400M supply support cost with various fleet sizes for an aircraft availability of 80%, as aimed by the Turkish Air Force. Next, it presents the results of individual experiments. Each experiment result-set consists of the shopping list and the cost vs. availability curve for corresponding fleet size. Finally, the chapter concludes with interpreting the results, in order to answer the investigative questions.

Supply Support Cost

The previous chapter explained the research design, how ASM was used, and how the experiments were conducted. In general, this study develops an ASM model for the A400M aircraft with various fleet sizes, and compares the results, in order to determine the optimal spare part mix. For each experiment, ASM was run with corresponding scenario. The aircraft availability goal was set to 80%. ASM provides various types of output, such as supply support cost, shopping list, and cost vs. availability curve. Achieved availability rates and supply support costs of the experiments are shown in Table 5.

Table 5: Supply Costs of Various Fleet Sizes

Scenario	Hours/Day	Fleet Size	Achieved Availability	Supply Cost
1	18.06	10	80.10%	$34,478,726
2	16.25	9	80.14%	$32,569,863
3	12.64	7	80.10%	$28,574,232
4	5.42	3	80.06%	$20,574,199
5	1.81	1	80.10%	$15,194,388

In the first experiment, the scenario was set up for a fleet size of 10 aircraft with 18.06 FH per day. ASM was run to calculate the optimal spare mix for the aircraft availability goal of 80%. Table 5 shows that supply cost of sustaining a fleet of 10 aircraft is $34,478,726. Figure 16 indicates that aircraft sustainment cost is linearly correlated with fleet size.

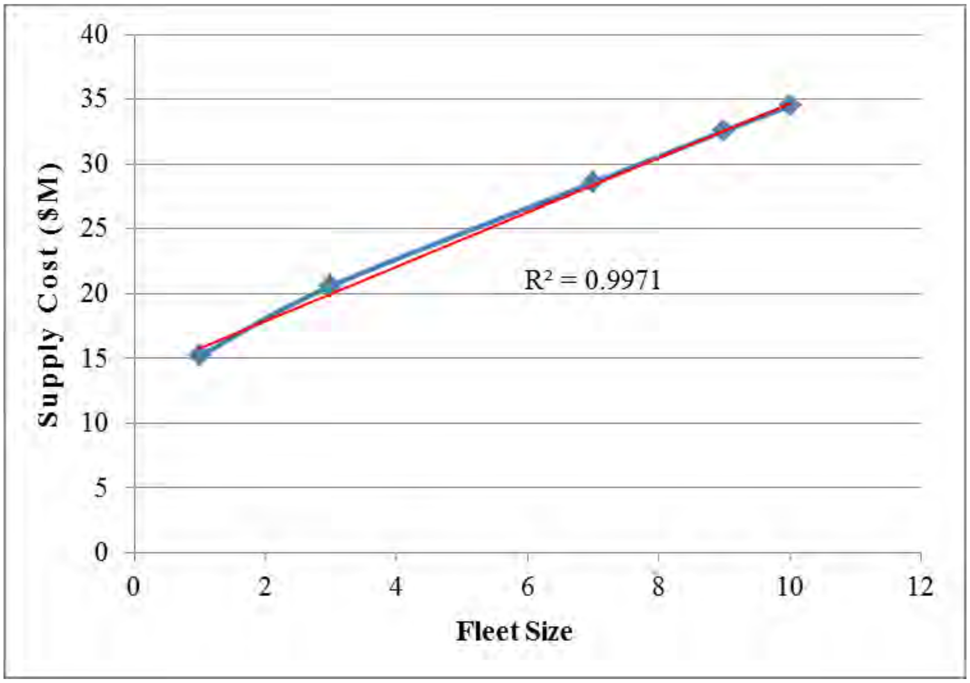


Figure 16: Fleet Size vs. Supply Cost

A simple linear regression is conducted, in order to determine the relation between fleet size and sustainment cost. Equation 12 shows the suggested regression equation. Even though having no aircraft does not have a supply cost associated with it, the intercept is assumed to exist for better estimation. Therefore, this regression model is only valid for fleet sizes that are greater than zero.

$$Supply\ Cost = Intercept + \beta * Fleet\ Size \tag{12}$$

Analysis of the regression results indicates that the predictor (fleet size) explains 99% of the variance ($R^2 = 0.99,\ F(1,3) = 1039.03,\ p < 0.001$). The final equation is shown in Equation 13. Both intercept and slope are statistically significant ($p < 0.001$).

$$Supply\ Cost = 13{,}627{,}862.80 + 2{,}108{,}403.13 * Fleet\ Size \tag{13}$$

Regression analysis, analysis of variance (ANOVA), regression coefficients and confidence intervals for the coefficients are shown in Table 6 to Table 9 respectively.

Table 6: Regression Statistics

Multiple R	0.998559475
R Square	0.997121026
Adjusted R Square	0.996161368
Standard Error	506,656.49
Observations	5

Table 7: Analysis of Variance (ANOVA)

	df	SS	MS	F	Significance F
Regression	1	2.66722E+14	2.66722E+14	1,039.04	6.56177E-05
Residual	3	7.70102E+11	2.56701E+11		
Total	4	2.67492E+14			

Table 8: Regression Coefficients

	Coefficients	Standard Error	t Stat	P-value
Intercept	13,627,862.80	453,167.34	30.07247342	8.07676E-05
Fleet Size	2,108,403.13	65,409.07	32.23410889	6.56177E-05

Table 9: Confidence Intervals

	Lower 95%	Upper 95%	Lower 99.0%	Upper 99.0%
Intercept	12,185,682.07	15,070,043.53	10,980,953.46	16,274,772.14
Fleet Size	1,900,242.28	2,316,563.99	1,726,354.68	2,490,451.59

Regression analysis indicates that the A400M fleet's sustainment cost is based at $13,627,862.80, and each aircraft increases the cost by $2,108,403.13. Additional budget requirement of an aircraft varies between $1,726,354.68 and $2,490,451.59 at 99% confidence level.

Results of Individual Experiments

For each experiment, ASM created the optimal spare mix for the goal of 80% aircraft availability, and also the cost vs. availability curve.

The cost vs. availability curves of individual experiments are shown in Figure 17 through Figure 21. In these figures, the horizontal axis represents the cost in millions of dollars, while the vertical axis represents the fleet availability.

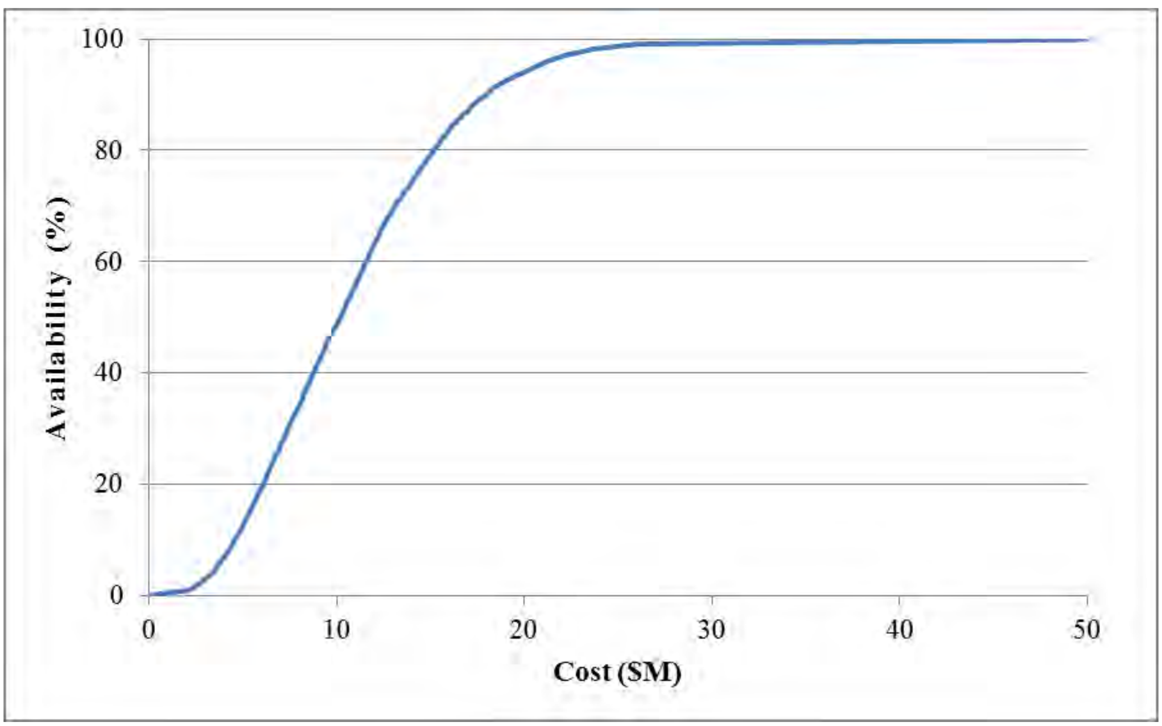


Figure 17: The Cost vs. Availability Curve of One Aircraft

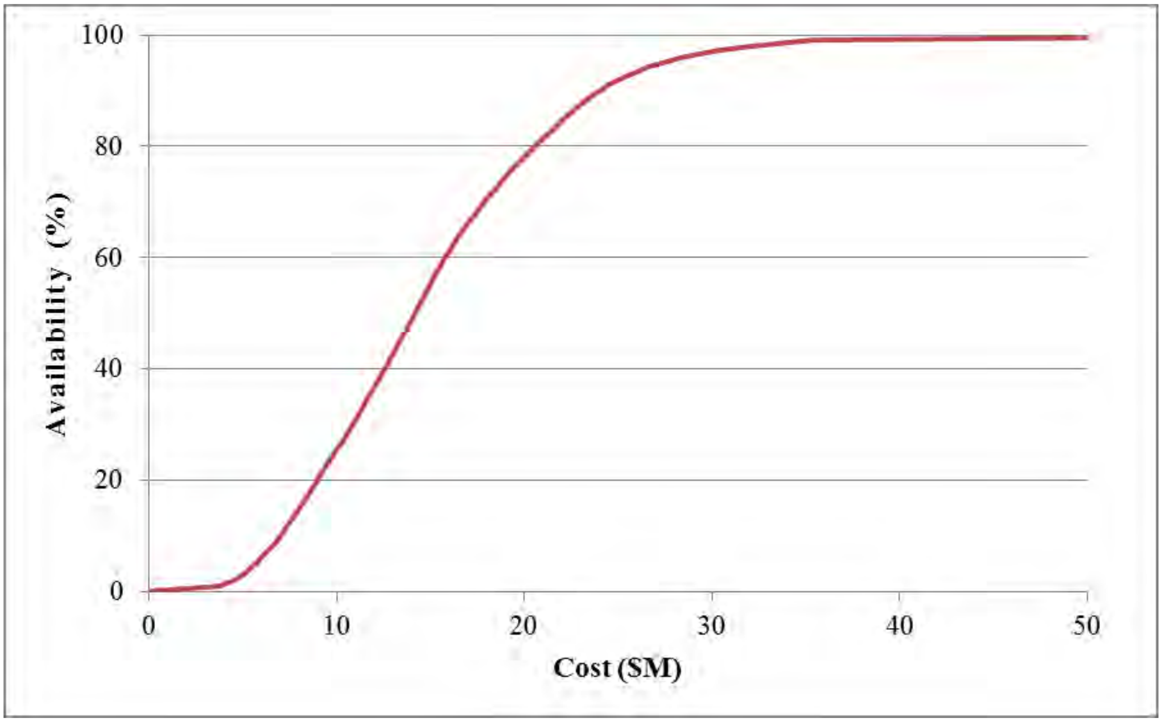


Figure 18: The Cost vs. Availability Curve of Three Aircraft

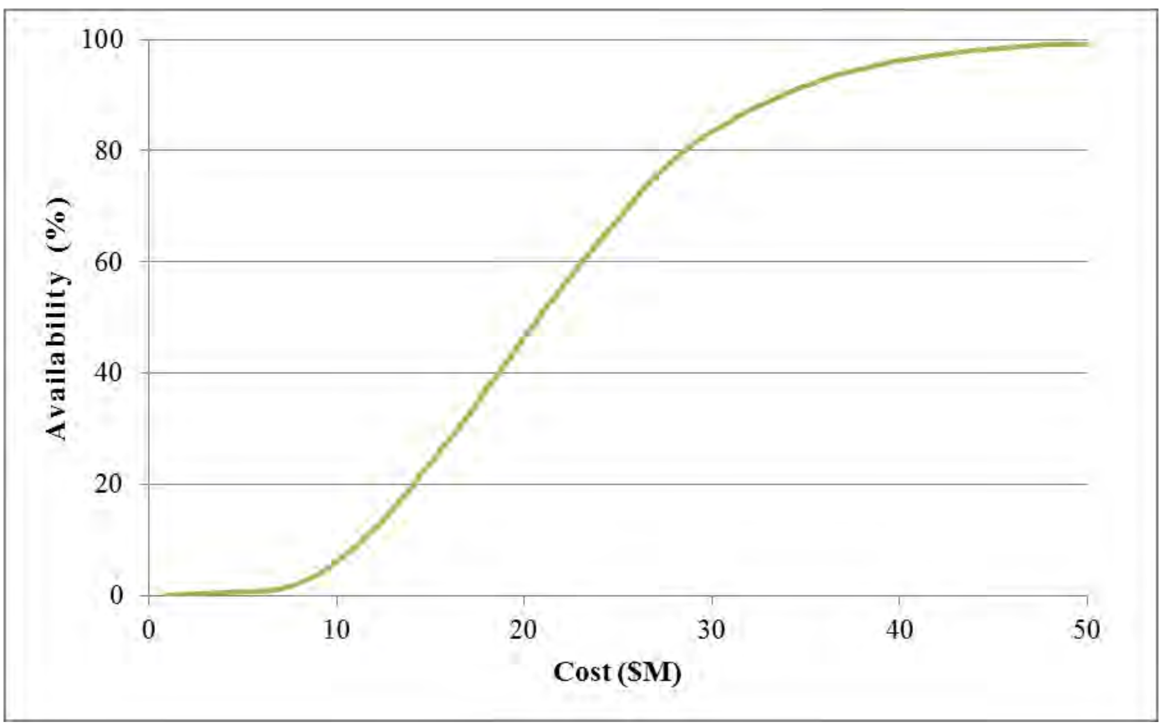


Figure 19: The Cost vs. Availability Curve of Seven Aircraft

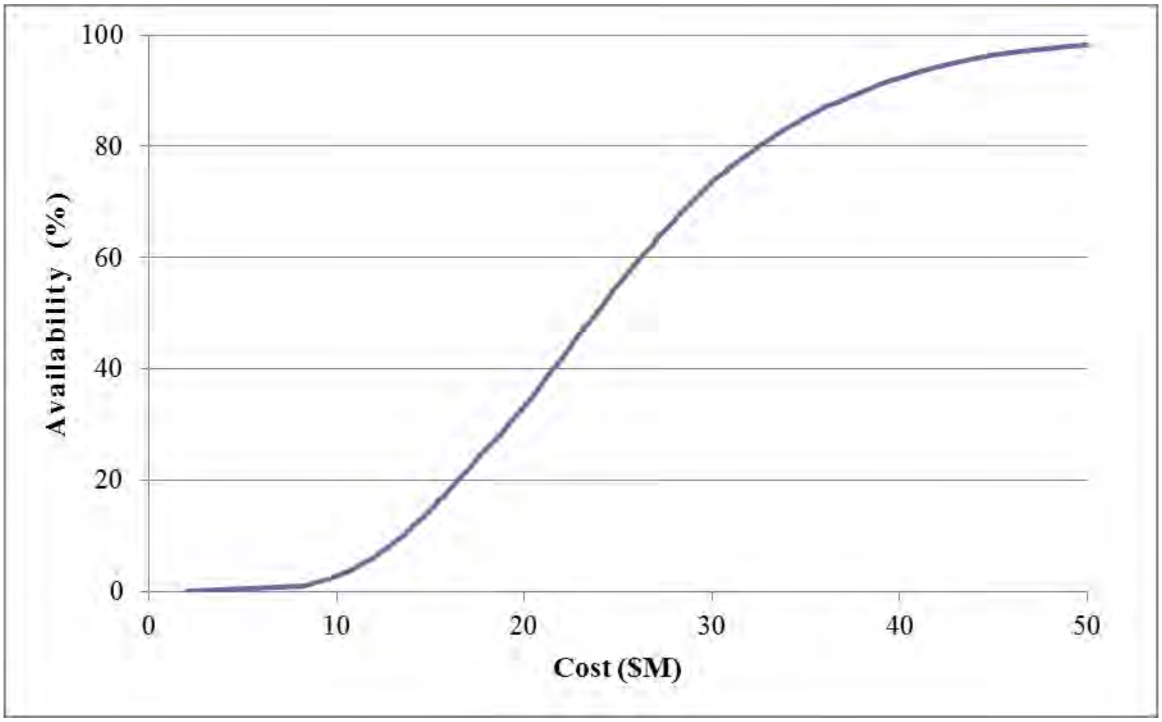


Figure 20: The Cost vs. Availability Curve of Nine Aircraft

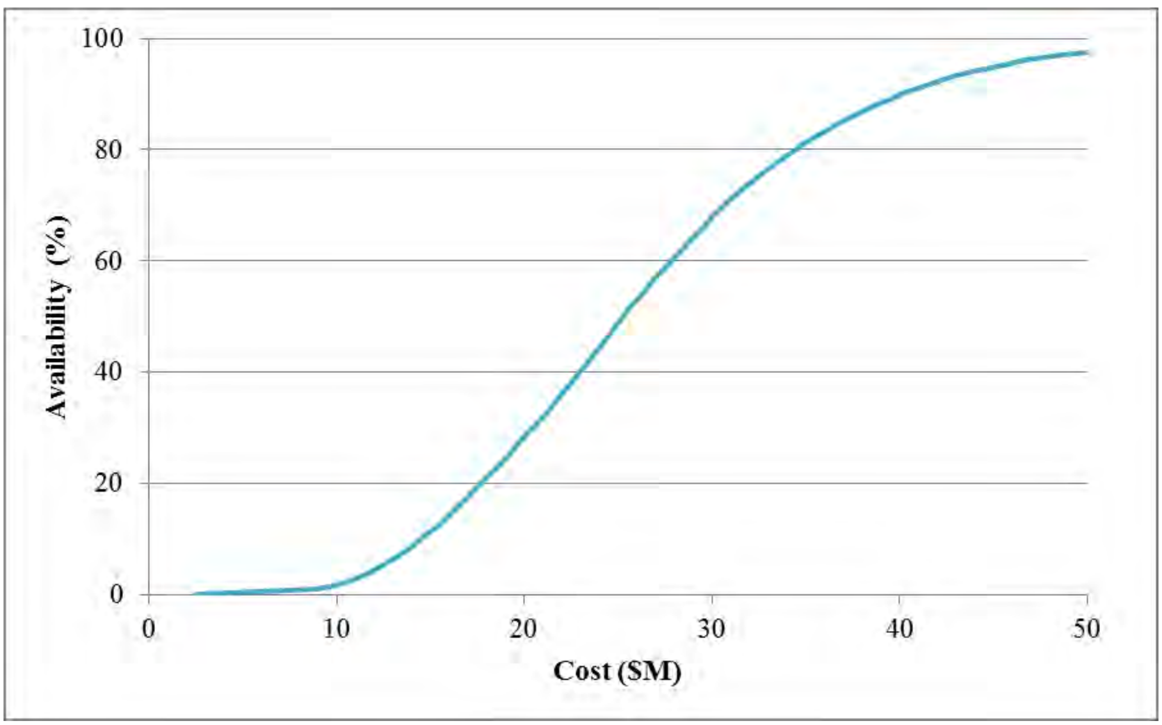


Figure 21: The Cost vs. Availability Curve of Ten Aircraft

Effects of Aircraft Delivery

The supply support cost of the A400M and the cost vs. availability curve are affected by each aircraft delivery. ASM experiments were conducted for the goal of 80% aircraft availability. Effects of aircraft deliveries are shown in Table 5 and Figure 16. As Equation 13 shows, the supply cost has a base of $13,627,862.80, and each aircraft delivery increases the cost by $2,108,403.13. The cost vs. availability curves of individual experiments are shown in Figure 17 through Figure 21. These five figures are combined into Figure 22. In this figure, the horizontal axis represents the cost in millions of dollars, while the vertical axis represents the fleet availability.

Figure 22 provides sufficient information to assess the effects of aircraft delivery on the cost vs. availability curve. As shown in this figure, single aircraft (the curve on the very left) requires the least amount of spare part investment to sustain desired aircraft availability. As mentioned before, the curve does not follow a linear trend; instead it starts with a low slope value, shows increasing marginal rate of return, then follows a linear line, and ends with a diminishing marginal rate of return. As the fleet size increases; the curve goes to the right, making it more expensive to obtain the same availability rate. The initial part of the curve extends with the fleet size. For example for a fleet size of ten aircraft, almost no practical aircraft availability is achieved until $10M threshold. The fleet size also decreases the slope of the curve, making it more costly to increase the availability. It is important to note that as the aircraft availability increases, the cost of availability improvement increases drastically, due to diminishing marginal rate of return. The curves go apart as the availability increases, and this makes it more expensive to sustain additional aircraft.

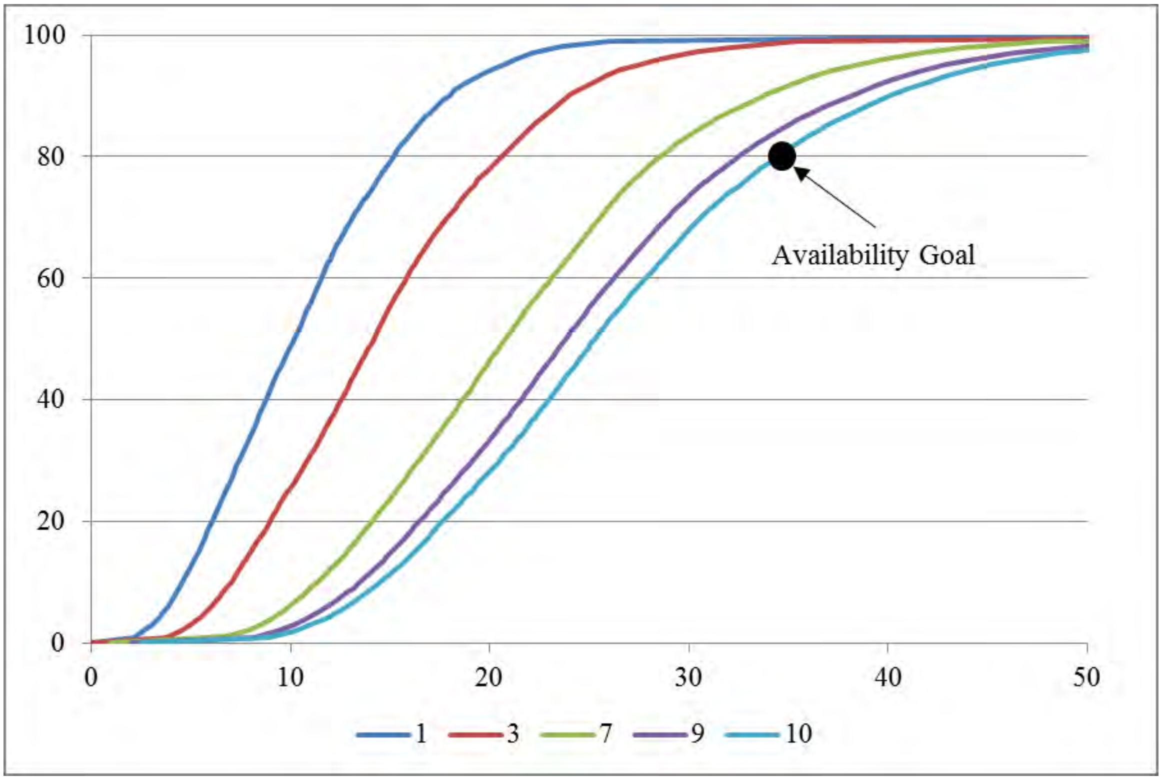


Figure 22: Effects of Aircraft Delivery on the Cost vs. Availability Curve

The Turkish Air Force initially aims to obtain 80% of aircraft availability for the A400M. ASM shows that having a fleet availability of 80% for the A400M requires a spare part investment of $34,478,726. Figure 22 reveals that if the Turkish Air Force incurs the same amount of spare part investment at the beginning of delivery period, higher availability rates can be obtained in the early phases. Table 10 and Figure 23 show the availability rates which are achievable with the same spare part investment.

Table 10: Achievable Aircraft Availability Rates

Fleet Size	Aircraft Availability
1	99.00%
3	98.00%
7	90.01%
9	83.38%
10	80.10%

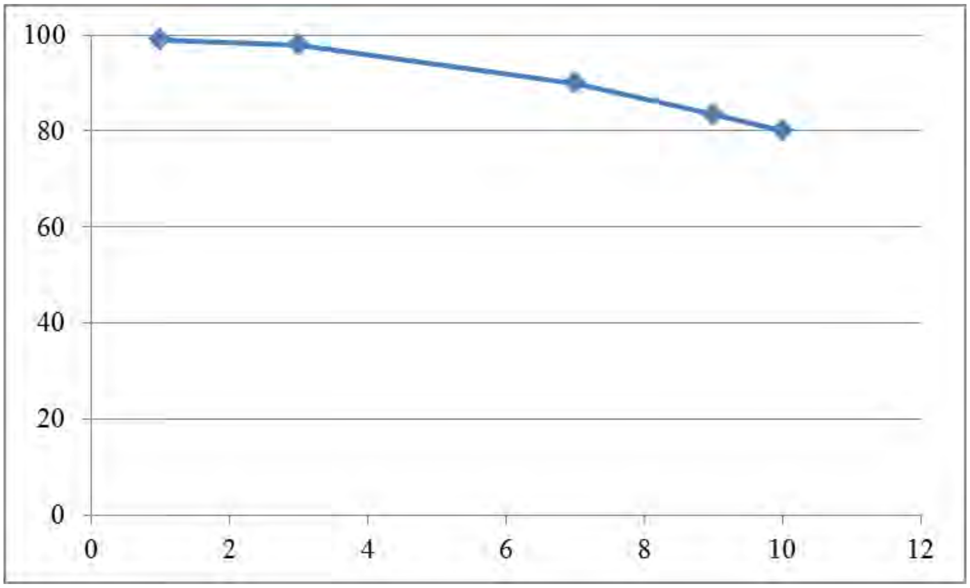


Figure 23: Fleet Size vs. Achievable Aircraft Availability Rates

Supply Support Cost Distribution

Like many other modern aircraft, the A400M consists of several systems and subsystems. The data provided by the A400M Procurement Project Group consists of 300 LRUs from 5 different systems of the aircraft. Table 11 shows the supply support cost distribution for various fleet sizes. Figure 24 shows the distribution for 10 aircraft with an availability goal of 80%. As shown in Table 11 and Figure 24, System 5 is the main cost driver for the A400M with one third of the supply cost.

Table 11: Supply Cost Distribution for Various Fleet Sizes

	Fleet Size				
Systems	**1 Aircraft**	**3 Aircraft**	**7 Aircraft**	**9 Aircraft**	**10 Aircraft**
1	12%	10%	9%	8%	8%
2	11%	12%	16%	16%	16%
3	24%	21%	19%	19%	19%
4	19%	20%	20%	20%	20%
5	33%	36%	36%	37%	37%
Total	100%	100%	100%	100%	100%

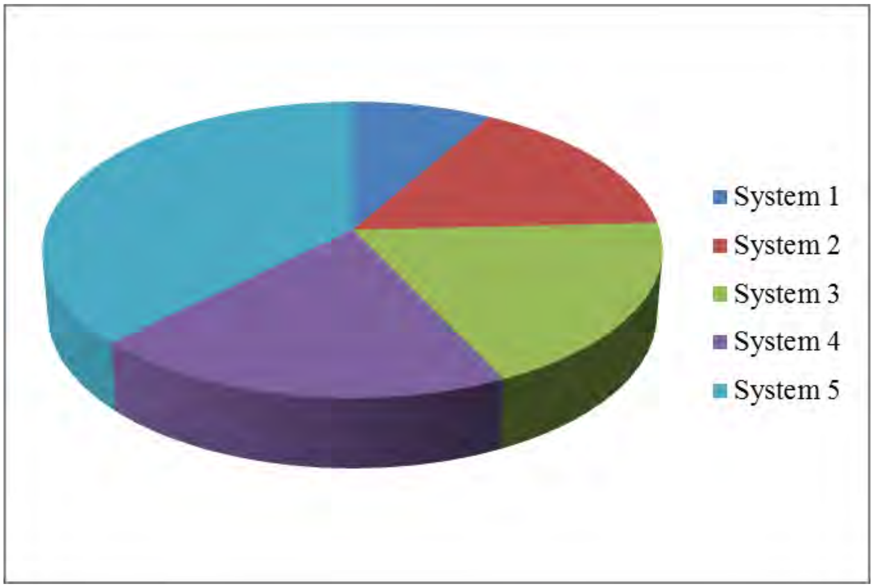


Figure 24: Supply Support Cost Distribution for the A400M Fleet

The Optimal Aircraft Availability

For a civilian company, the balance between aircraft availability and cost can be easily obtained on the financial balance sheets. In the military, however, the issue of financial interest is replaced by national security. Failure to achieve the operational requirements may result in fatal consequences. There is no monetary value associated with the availability rate. Therefore, the balance between availability and cost is harder to achieve, and yet still possible.

In order to discover the optimal aircraft availability, this research utilizes benefit-to-cost ratio (BCR), which is defined as the percentage of aircraft availability per million dollars. Figure 25 shows how BCR changes with availability rate for a fleet of ten aircraft. On this figure, the horizontal axis shows aircraft availability, while the vertical axis shows the benefit-to-cost ratio associated with this availability level.

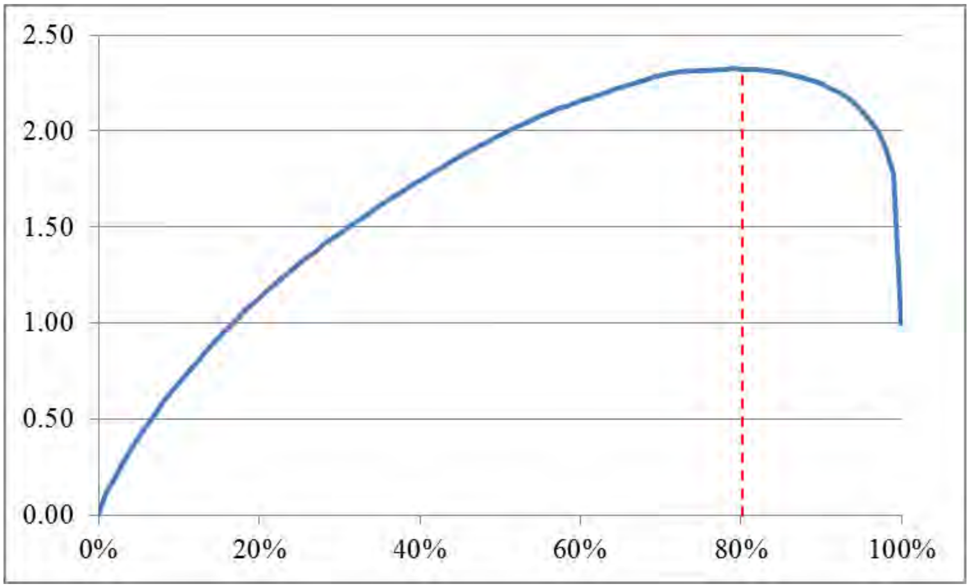


Figure 25: Aircraft Availability vs. BCR

As shown in Figure 25, BCR value increases slowly, creates a plateau at 2.32 between 75% and 82% aircraft availability, and then falls rapidly. The highest BCR value yields 2.32% aircraft availability for the A400M aircraft per each million dollars spent on the spare support. It is important to note that there is no monetary value associated with the availability of the military aircraft and BCR approach is not a powerful substitute for marginal analysis approach. Five availability rates are compared, starting from 70% with 5% steps up to 90%. Table 12 shows the considered rates, associated costs, and corresponding benefit-to-cost ratios for a fleet of 10 aircraft. Aircraft availability of 80% has the greatest benefit-to-cost ratio, as shown in Table 12.

Table 12: Benefit-to-Cost Ratio of Various Availability Rates

Availability	Cost ($M)	BCR
70%	30.695	2.292
75%	32.390	2.316
80%	34.479	2.323
85%	36.887	2.305
90%	40.134	2.244

Summary

This chapter presented the results of the experiments, and analysis. The chapter began by presenting the A400M supply support cost with various fleet sizes for an aircraft availability of 80%. Next, it presented the results of individual experiments. Each experiment result-set consists of the shopping list and the cost vs. availability curve for corresponding fleet size. Finally, the chapter concluded with the analysis and interpretation of the results from Chapter III.

V. Conclusions and Recommendations

Chapter Overview

This thesis research is conducted with the goal of determining which spare parts should be procured for the A400M aircraft by the Turkish Air Force, in order to attain the balance between aircraft availability and the cost of spare parts. In order to be successful in this goal, four investigative questions are posed by the research.

1. What is the cost vs. availability curve of the A400M fleet with the Turkish Air Force's maintenance structure?
2. What is the optimum aircraft availability of the A400M? Is the aircraft availability goal of 80% viable?
3. How does each aircraft delivery affect the supply support cost and the cost vs. availability curve?
4. What is the supply cost distribution among the A400M subsystems?

This chapter begins by discussing the answers to these investigative questions. The chapter continues with the conclusions that can be drawn from these answers. Next, it presents recommendations for which spare parts should be procured. Finally, the chapter identifies areas for future research in the subject.

Conclusions

This section looks at each of the investigative questions and draws conclusions based on the analysis. Later, the research question is answered.

1. **What is the cost vs. availability curve of the A400M fleet with the Turkish Air Force's maintenance structure?**

Figure 26 shows the cost vs. availability curve of the A400M fleet with 10 aircraft, under the Turkish Air Force's maintenance structure.

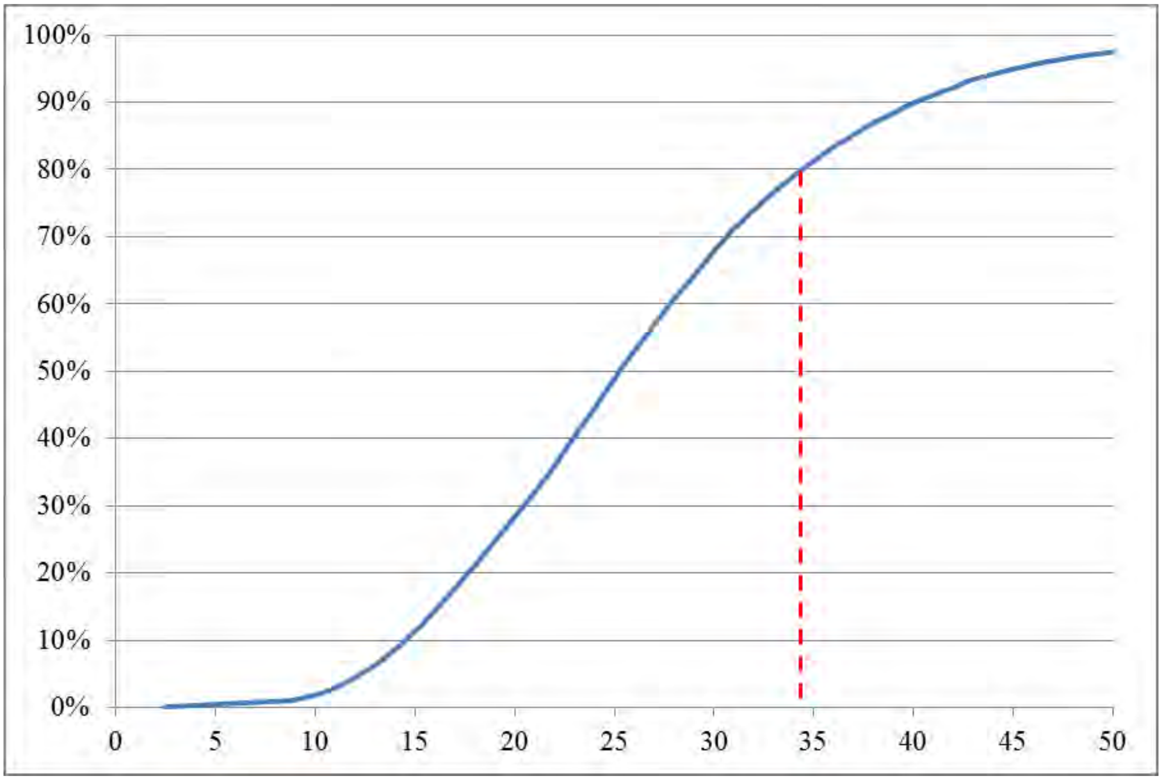


Figure 26: The Cost vs. Availability Curve of the A400M Fleet

The curve follows an intuitive pattern; increases slowly up to 10%, then follows a linear trend between 10% and 70%, and finally shows a diminishing marginal rate of return between 70% and up.

The cost vs. availability curve quantifies the supply cost of availability, and provides critical information about tradeoff opportunities. The military decision makers, equipped with this information, can make tradeoffs between availability and cost, and obtain a better use of the scarce resources.

2. What is the optimum aircraft availability of the A400M? Is the aircraft availability goal of 80% viable?

In order to discover the optimal availability, this research utilizes benefit-to-cost ratio (BCR), which is defined as the percentage of availability per million dollars.

Analysis shows that BCR value increases with aircraft availability, forms a plateau between 78% and 81% availability, and then falls rapidly. Availability vs. BCR curve is shown in Figure 25 on page 67.

Five availability rates are compared, starting from 70% up to 90% with 5% incremental steps. As shown in Table 12, aircraft availability of 80% has the greatest benefit-to-cost ratio, among compared availability rates. Therefore, it provides the optimal availability for the supply cost. The Turkish Air Force's initial availability goal is viable.

3. How does each aircraft delivery affect the supply support cost and the cost vs. availability curve?

Each aircraft delivery shifts the cost vs. availability curve to the right, which results in increased supply support cost.

Simple regression analysis of the supply support cost indicates that the predictor (fleet size) explains 99% of the supply cost variance ($R^2 = 0.99,\ F(1,3) = 1039.03,$ $p < 0.001$). Both intercept and slope are statistically significant ($p < 0.001$). The final equation is shown in Equation 13. Regression analysis indicates that the A400M fleet's sustainment cost is based at $13,627,862.80, and each aircraft increases the cost by $2,108,403.13. Additional budget requirement of an aircraft varies between $1,726,354.68 and $2,490,451.59 at 99% confidence level.

The cost vs. availability curves of individual experiments are combined into Figure 22. As shown in this figure, the cost vs. availability curve goes to the right as the fleet size increases. In order to maintain the same level of aircraft availability, additional spare part investment should be made upon aircraft deliveries.

ASM shows that having a fleet availability of 80% requires a spare part investment of $34,478,726. The Turkish Air Force may choose to incur this inventory investment in the first year, in order to leverage buying power. Figure 22 reveals that if the investment is made in the first year, higher availability rates (up to 99%) can be obtained in the early phases of delivery schedule. Table 10 and Figure 23 show the availability rates which are achievable with the same spare part investment.

4. What is the supply cost distribution among the A400M subsystems?

The data provided by the A400M Procurement Project Group consists of details about 300 LRUs from 5 different systems of the A400M. The supply support cost distribution provides a bearing on where to focus availability improvements efforts. Figure 24 shows the distribution for 10 aircraft with an availability goal of 80%. As shown in Figure 24; the System 1 requires the least amount of investment with 8%, while the System 5 is the main cost driver for the A400M with 37% of the supply cost. Process improvement and cost reduction projects should focus on System 5 for the best results.

Conclusions which are drawn from the investigative questions provide sufficient information to answer the research question.

Which spare parts should the Turkish Air Force procure for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts?

The cost vs. availability curve of the A400M (Figure 26) indicates that the optimal fleet availability is 80%, and this availability rate requires a spare part investment of $34,478,726. With the delivery of each aircraft, the cost vs. availability curve shifts to the right, which results in increased supply support cost to be incurred, in order to maintain the same availability. System 5 is the main cost driver for the A400M with 37% of the supply support cost, while System 1 only accounts for 8%.

In order to obtain the balance between aircraft availability and the cost of spare parts, the Turkish Air Force should sustain the A400M fleet at 80% availability. Table 13 shows that in order to achieve this availability rate; the first year requires a spare part investment of $15,194,388 with the purchase of 339 LRUs. The shopping list is provided in Appendix B. The second year requires an additional budget of $5,379,811 to purchase 108 additional LRUs. The shopping list of additional spares is provided in Appendix C. Information about the remaining period is provided in Table 13.

Table 13: Spare Part Requirements of the A400M Aircraft

Fleet Size	Availability	Additional Cost	Additional LRUs	Shopping List
0	0	$0	0	None
1	80.10%	$15,194,388	339	Appendix B
3	80.06%	$5,379,811	108	Appendix C
7	80.10%	$8,000,033	132	Appendix D
9	80.14%	$3,995,631	58	Appendix E
10	80.10%	$1,908,863	32	Appendix F

Recommendations

This research is established on a logistician perspective, and it is founded on the key assumption that the aircraft availability is determined only by the spare part support and supply structure. This key assumption enables performing relevant inventory management techniques to gain insights about the A400M. Within its assumption limits, this study provides sufficient information to answer the research question. In order to obtain the balance between aircraft availability and the cost of spare parts, the Turkish Air Force should sustain the A400M fleet at 80% availability.

However, as mentioned in the literature review, the aircraft availability depends on several factors, such as maintenance work force, ground equipment, training, aircraft operations and more. These factors are assumed constant over the planning horizon of 5 years, in order to facilitate this study. The A400M program is currently in the initial logistics provisioning phase. In this phase, the Turkish Air Force is gathering the necessary support products, such as spare parts, ground equipment, and technical documentation. In the next phase, the Turkish Air Force will start gaining in-house repair and production capabilities. The maintainability and reliability of the A400M fleet will be affected by this adoption period following a learning curve. Local production of the spare parts, interaction with other aircraft platforms, changes in the mission requirements and other factors will also affect the maintainability and reliability. In order to capture these effects and provide accurate information, a follow-on study should be accomplished with up to date and detailed data. It is also important to note that availability of the historical data yields more realistic results, because the design reliability and field reliability can be drastically different.

The initial provisioning phase can provide several cost saving opportunities. Procurement of spare parts is made in bulk quantities and buying power can be used to obtain discounts. ASM shows that having a fleet availability of 80% requires a spare part investment of $34.5M. The Turkish Air Force may choose to incur this inventory investment in the first year, in order to leverage buying power. Figure 22 reveals that if the investment is made in the first year, higher availability rates (up to 99%) can be obtained in the early phases of delivery schedule. Table 10 and Figure 23 show the availability rates which are achievable with the same spare part investment.

The supply cost distribution among the A400M subsystems is shown in Figure 24. The distribution shows that the System 5 accounts for 37% of the supply cost. The Turkish Air Force should focus on System 5 to mitigate the cost of availability.

Future Research

This thesis study is a preliminary research, in the sense that it provides an initial glance at the A400M's characteristics with ASM. Similar research could be done on other weapon-systems as well. This study merely depends on Airbus's reliability estimates, and it can be improved in several ways by future research efforts.

A future study could be conducted by improving the existing data set. This improvement could be done in two fundamental levels: introduction of enhanced and detailed data, or introduction of the Turkish repair facilities. As mentioned before, this study is considered as seminal research and it is conducted with a limited data set, due to lack of historical data and data confidentiality. The provided data set is based on Airbus's reliability estimates, and these estimates might change drastically by aircraft operations and geographic location. Improvement of the data set would improve the accuracy of the results.

On the other hand, the Turkish Air Force will gain repair capabilities as the A400M program advances. Introduction of the Turkish repair facilities would change the very nature of the logistic pipeline, such as order & shipment time, repair time, and number of assets in the pipeline. A future study could compare the changes and quantify the benefits of candidate improvement projects. Furthermore, this study is performed with ASM, in order to enable further research to be conducted with minimum effort.

Summary

This thesis study aimed to find the optimal spare part mix for the A400M aircraft, in order to attain the balance between aircraft availability and the cost of spare parts, under the Turkish Air Force's maintenance structure. The study started with a brief background of the A400M aircraft and its advanced features. The literature review yielded that logistic operations have significant influence on the aircraft availability and sufficient spare part support is essential to achieve desired availability rates. In order to calculate the optimal spare part mix, the study used the Aircraft Sustainability Model (ASM) by LMI. ASM provides the optimal cost vs. availability curve and it is widely used for provisioning, replenishment, and deployment spares decisions. In this study, an ASM model was developed for the A400M aircraft with various fleet sizes, and the results were compared to determine the optimal spare part mix. The results led to the conclusion that the optimal fleet availability is 80%, and this availability rate requires a spare part investment of $34,478,726. It was found that if the inventory investment is made in the first year, higher availability rates (up to 99%) can be obtained in the early phases of the aircraft delivery schedule. It was also found that the System 1 requires the least amount of investment with 8%, while the System 5 is the main cost driver for the A400M fleet with 37% of the supply cost.

Appendix A

A subset of the input data is shown in Table 14. Due to space constraints, some fields are omitted. For detailed information about ASM input file structure, refer to ASM User Manual (Kline and others, 2001)

R Type = Type of the item (LRU or SRU).
NSN = National stock number.
Cost = Unit cost of the item.
QPA = Quantity per aircraft of the item.
Bud Code = Budget code (user specified). This field was used for analyzing the distribution of the supply support cost among systems of the A400M.
OST P = Order and ship time for steady-state/peace.
DRT P = Depot repair time for steady-state/peace.
TOIMDR P = Demand per operating hour for steady-state/peace.

Table 14: A Subset of the ASM Input Data

R Type	NSN	Cost	QPA	Bud Code	OST P	DRT P	TOIMDR P
LRU	LRU-111	36340	1	1	8	15	0.00028292
LRU	LRU-112	36816	1	3	8	15	0.00014553
LRU	LRU-113	35300	4	4	8	15	0.00030628
LRU	LRU-114	25310	1	1	8	10	0.0001212
LRU	LRU-115	32929	4	2	8	15	0.00011869
LRU	LRU-116	29810	2	3	8	15	0.00015003
LRU	LRU-117	30588	2	3	8	15	0.0000404
LRU	LRU-118	19218	2	5	8	10	0.00006272
LRU	LRU-119	24588	1	4	8	10	0.00011848
LRU	LRU-120	21054	5	5	8	15	0.00036144
LRU	LRU-121	19884	2	5	8	15	0.00032128
LRU	LRU-122	20608	2	1	8	15	0.00029628
LRU	LRU-123	23789	2	4	8	45	0.00024507
LRU	LRU-124	18091	2	3	8	10	0.00028886
LRU	LRU-125	24509	3	2	8	15	0.00004378
LRU	LRU-126	27601	2	3	8	30	0.00006252
LRU	LRU-127	24266	1	2	8	15	0.00028072
LRU	LRU-128	28646	1	3	8	10	0.00011997
LRU	LRU-129	18730	1	4	8	10	0.0001333
LRU	LRU-130	26442	1	2	8	10	0.00010483

Appendix B

Table 15 shows the shopping list for one aircraft.

Table 15: The Shopping List for One Aircraft

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU001	5	1		LRU119	4	1		LRU209	4	2
LRU004	1	1		LRU120	5	2		LRU210	5	1
LRU007	5	1		LRU121	5	1		LRU211	4	1
LRU008	5	1		LRU122	1	1		LRU214	1	1
LRU009	5	1		LRU123	4	1		LRU215	1	1
LRU010	5	1		LRU124	3	1		LRU216	2	3
LRU011	3	2		LRU125	2	1		LRU217	5	2
LRU012	3	1		LRU126	3	1		LRU218	1	1
LRU013	4	1		LRU127	2	1		LRU219	1	2
LRU014	3	1		LRU128	3	1		LRU220	3	1
LRU015	5	1		LRU129	4	1		LRU222	3	3
LRU016	3	1		LRU130	2	1		LRU223	2	1
LRU017	5	2		LRU131	2	1		LRU224	2	1
LRU020	3	1		LRU132	5	1		LRU225	5	2
LRU022	2	5		LRU133	1	1		LRU226	5	1
LRU023	5	6		LRU134	5	1		LRU227	1	1
LRU024	1	1		LRU135	3	1		LRU228	4	2
LRU025	3	1		LRU136	2	1		LRU229	4	1
LRU026	4	1		LRU137	3	1		LRU230	4	1
LRU027	1	1		LRU138	1	1		LRU231	1	2
LRU028	3	1		LRU139	2	1		LRU232	5	2
LRU029	2	1		LRU140	5	1		LRU233	2	2
LRU031	3	1		LRU141	3	1		LRU234	5	2
LRU033	5	1		LRU142	2	1		LRU235	1	2
LRU034	1	1		LRU144	2	1		LRU236	5	2
LRU035	4	1		LRU145	4	1		LRU237	4	2
LRU036	5	1		LRU146	5	1		LRU238	2	1
LRU038	4	1		LRU147	4	1		LRU239	1	2
LRU039	4	1		LRU149	4	1		LRU240	5	1
LRU040	3	1		LRU150	3	1		LRU241	4	2
LRU042	4	1		LRU151	2	1		LRU242	2	1
LRU043	5	1		LRU152	3	4		LRU243	5	1
LRU044	2	1		LRU153	1	2		LRU244	1	1
LRU045	5	1		LRU154	5	1		LRU245	1	1

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU046	1	1		LRU155	4	1		LRU246	4	1
LRU049	5	1		LRU156	3	1		LRU247	1	1
LRU050	3	1		LRU157	3	1		LRU248	2	1
LRU051	1	1		LRU158	2	1		LRU249	2	1
LRU052	3	1		LRU159	2	1		LRU250	1	1
LRU056	4	1		LRU160	4	1		LRU251	4	1
LRU057	4	1		LRU161	4	1		LRU252	2	3
LRU058	1	1		LRU162	2	1		LRU253	3	2
LRU060	5	1		LRU163	3	1		LRU254	5	1
LRU062	4	1		LRU164	3	1		LRU255	4	1
LRU063	3	2		LRU165	3	1		LRU256	3	1
LRU064	4	1		LRU167	1	1		LRU257	5	3
LRU065	4	2		LRU168	4	1		LRU258	1	1
LRU066	5	1		LRU169	2	1		LRU259	5	1
LRU067	4	1		LRU170	2	1		LRU260	3	3
LRU068	3	1		LRU171	4	1		LRU261	2	1
LRU071	3	1		LRU172	4	1		LRU262	4	1
LRU072	4	1		LRU173	3	1		LRU263	1	1
LRU073	2	2		LRU174	3	1		LRU264	3	2
LRU074	3	1		LRU175	3	1		LRU266	1	1
LRU075	3	1		LRU176	3	1		LRU267	4	1
LRU076	1	1		LRU177	5	1		LRU268	3	1
LRU077	1	1		LRU178	2	1		LRU269	1	1
LRU078	3	2		LRU179	1	4		LRU270	1	2
LRU084	4	1		LRU180	3	4		LRU271	1	1
LRU085	3	1		LRU181	5	1		LRU272	2	1
LRU086	4	11		LRU182	4	1		LRU273	4	1
LRU088	1	1		LRU183	3	1		LRU274	1	1
LRU089	3	1		LRU184	5	1		LRU275	5	1
LRU090	1	1		LRU185	3	2		LRU276	5	2
LRU092	4	1		LRU186	4	2		LRU277	3	1
LRU093	5	1		LRU187	2	1		LRU278	4	1
LRU095	1	1		LRU188	2	1		LRU279	4	1
LRU096	4	1		LRU189	1	1		LRU280	1	1
LRU098	5	2		LRU190	2	1		LRU281	3	1
LRU099	3	1		LRU191	2	1		LRU282	4	1
LRU101	4	2		LRU192	3	1		LRU283	4	1
LRU102	2	1		LRU193	5	1		LRU284	3	1
LRU103	3	1		LRU194	3	1		LRU285	2	1

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU104	5	1		LRU195	3	1		LRU286	3	1
LRU105	1	1		LRU196	1	1		LRU287	3	2
LRU106	4	2		LRU197	1	1		LRU288	1	2
LRU107	4	1		LRU198	5	1		LRU289	5	1
LRU108	5	1		LRU199	5	1		LRU290	2	2
LRU109	3	1		LRU200	5	1		LRU291	3	2
LRU110	2	2		LRU201	2	1		LRU292	1	1
LRU111	1	1		LRU202	3	1		LRU293	4	1
LRU112	3	1		LRU203	2	1		LRU294	3	1
LRU113	4	1		LRU204	4	1		LRU295	1	1
LRU114	1	1		LRU205	1	1		LRU297	3	2
LRU115	2	1		LRU206	4	1		LRU298	4	1
LRU116	3	1		LRU207	4	1		LRU299	2	2
LRU117	3	1		LRU208	1	1		LRU300	2	2
LRU118	5	1								

Appendix C

Table 16 shows the shopping list for three aircraft.

Table 16: The Shopping List for Three Aircraft

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU001	5	1		LRU113	4	1		LRU200	5	1
LRU010	5	1		LRU121	5	1		LRU201	2	1
LRU022	2	4		LRU122	1	1		LRU210	5	1
LRU023	5	5		LRU123	4	1		LRU216	2	1
LRU034	1	1		LRU124	3	1		LRU217	5	1
LRU037	5	1		LRU133	1	1		LRU221	1	1
LRU038	4	1		LRU142	2	1		LRU222	3	1
LRU040	3	1		LRU143	3	1		LRU225	5	1
LRU045	5	1		LRU148	4	1		LRU238	2	1
LRU050	3	1		LRU149	4	1		LRU241	4	1
LRU055	3	1		LRU150	3	1		LRU242	2	1
LRU056	4	1		LRU152	3	3		LRU246	4	1
LRU061	2	1		LRU154	5	1		LRU248	2	1
LRU063	3	1		LRU156	3	1		LRU251	4	1
LRU064	4	1		LRU160	4	1		LRU252	2	1
LRU065	4	1		LRU164	3	1		LRU256	3	1
LRU066	5	1		LRU166	5	1		LRU257	5	1
LRU068	3	1		LRU170	2	1		LRU260	3	1
LRU072	4	1		LRU179	1	3		LRU261	2	1
LRU079	5	1		LRU180	3	3		LRU262	4	1
LRU081	4	1		LRU182	4	1		LRU263	1	1
LRU083	2	1		LRU184	5	1		LRU275	5	1
LRU085	3	1		LRU186	4	1		LRU277	3	1
LRU086	4	11		LRU187	2	1		LRU278	4	1
LRU096	4	1		LRU193	5	1		LRU280	1	1
LRU097	2	1		LRU197	1	1		LRU285	2	1
LRU100	3	1		LRU198	5	1		LRU294	3	1
LRU102	2	1		LRU199	5	1		LRU298	4	1
LRU106	4	1								

Appendix D

Table 17 shows the shopping list for seven aircraft.

Table 17: The Shopping List for Seven Aircraft

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU006	2	1		LRU090	1	1		LRU225	5	1
LRU011	3	1		LRU094	2	1		LRU228	4	1
LRU015	5	1		LRU096	4	1		LRU229	4	1
LRU017	5	1		LRU098	5	1		LRU231	1	1
LRU022	2	8		LRU101	4	1		LRU232	5	1
LRU023	5	10		LRU105	1	1		LRU233	2	1
LRU030	1	1		LRU106	4	1		LRU236	5	1
LRU033	5	1		LRU110	2	1		LRU237	4	1
LRU035	4	1		LRU115	2	1		LRU239	1	1
LRU036	5	1		LRU120	5	1		LRU243	5	1
LRU038	4	1		LRU152	3	4		LRU245	1	1
LRU040	3	1		LRU153	1	1		LRU252	2	1
LRU042	4	1		LRU173	3	1		LRU253	3	1
LRU044	2	1		LRU179	1	3		LRU257	5	2
LRU045	5	1		LRU180	3	4		LRU258	1	1
LRU049	5	1		LRU185	3	1		LRU259	5	1
LRU053	4	1		LRU186	4	1		LRU260	3	1
LRU054	3	1		LRU188	2	1		LRU270	1	1
LRU059	3	1		LRU189	1	1		LRU271	1	1
LRU063	3	2		LRU202	3	1		LRU276	5	1
LRU065	4	2		LRU203	2	1		LRU279	4	1
LRU066	5	1		LRU205	1	1		LRU282	4	1
LRU069	2	1		LRU209	4	1		LRU287	3	1
LRU070	2	1		LRU211	4	1		LRU288	1	1
LRU073	2	1		LRU216	2	2		LRU290	2	1
LRU077	1	1		LRU217	5	2		LRU291	3	1
LRU078	3	1		LRU219	1	1		LRU292	1	1
LRU086	4	19		LRU222	3	1		LRU295	1	1
LRU088	1	1								

Appendix E

Table 18 shows the shopping list for nine aircraft.

Table 18: The Shopping List for Nine Aircraft

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU001	5	1		LRU098	5	1		LRU204	4	1
LRU011	3	1		LRU101	4	1		LRU215	1	1
LRU016	3	1		LRU103	3	1		LRU220	3	1
LRU017	5	1		LRU113	4	1		LRU222	3	1
LRU022	2	3		LRU120	5	1		LRU226	5	1
LRU023	5	5		LRU123	4	1		LRU234	5	1
LRU063	3	1		LRU136	2	1		LRU235	1	1
LRU065	4	1		LRU152	3	1		LRU241	4	1
LRU073	2	1		LRU164	3	1		LRU252	2	1
LRU076	1	1		LRU170	2	1		LRU260	3	1
LRU078	3	1		LRU179	1	2		LRU264	3	1
LRU080	1	1		LRU180	3	2		LRU273	4	1
LRU086	4	9		LRU193	5	1		LRU297	3	1
LRU091	4	1		LRU201	2	1		LRU299	2	1

Appendix F

Table 19 shows the shopping list for ten aircraft.

Table 19: The Shopping List for Ten Aircraft

NSN	System	Buy		NSN	System	Buy		NSN	System	Buy
LRU010	5	1		LRU109	3	1		LRU216	2	1
LRU022	2	2		LRU127	2	1		LRU217	5	1
LRU023	5	2		LRU150	3	1		LRU218	1	1
LRU038	4	1		LRU152	3	1		LRU231	1	1
LRU040	3	1		LRU154	5	1		LRU257	5	1
LRU048	1	1		LRU160	4	1		LRU267	4	1
LRU082	3	1		LRU179	1	1		LRU283	4	1
LRU086	4	5		LRU180	3	1		LRU285	2	1
LRU093	5	1		LRU187	2	1				

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
08 Mar 2012	Master's Thesis	04 Oct 2010 - 22 Mar 2012

4. TITLE AND SUBTITLE
Initial Spare Parts of the A400M Aircraft

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
TOPALOĞLU, İhsan, First Lieutenant, TurAF

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/ENS)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-LSCM-ENS-12-20

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Intentionally Left Blank

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT F
FURTHER DISSEMINATION ONLY AS DIRECTED BY THE TURKISH AIR FORCE 08 MAR 2012 OR HIGHER TURKISH DOD AUTHORITY

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The A400M is a new military transport aircraft, which is designed and built to fill the gap between strategic and tactical capabilities of modern air forces, among which is the Turkish Air Force. To be successful in this endeavor, high aircraft availability is essential. Aircraft availability is affected by selection of spare parts and components availability at the repair facilities. This thesis study seek to determine which spare parts the Turkish Air Force should procure for the A400M, in order to attain the balance between aircraft availability and the cost of spare parts. The Aircraft Sustainability Model (ASM) by LMI is chosen to calculate the essential spare part support. ASM provides the optimal cost vs. availability curve and it is widely used for provisioning, replenishment, and deployment spares decisions. In general, this study develops an ASM model for the A400M aircraft with various fleet sizes, and compares the results to determine the optimal spare part mix. Conclusions which are drawn from the ASM experiments and analysis provides sufficient information to construct the optimal cost vs. availability curve of the A400M aircraft under the Turkish Air Force's maintenance structure. This curve provides critical information for the military decision makers to determine tradeoffs between availability and cost, in order to obtain a better use of scarce resources. The study also provides important insights about the characteristics of the A400M aircraft, such as the optimal availability and the supply cost distribution among the A400M subsystems.

15. SUBJECT TERMS
AIRBUS A400M, INITIAL SPARE PARTS,

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Daniel D. Mattioda, Maj, Ph.D., USAF
					19b. TELEPHONE NUMBER *(Include area code)*
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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

9 May 2016

MEMORANDUM FOR RECORD (AFIT Security Office)

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SUBJECT: Request for Change of Distribution, DTIC # ADB378348

1. The Department of Operational Sciences requests that the Distribution statement for the thesis titled, "Initial Spare Parts of the A400M Aircraft" dated March 2012, be changed from "Distribution Statement F; Further Dissemination Only As Directed by the Turkish Air Force 08 Mar 2012 or Higher Turkish DoD Authority" to "Unlimited Distribution".

2. Reasoning – All participating states in A400M program have concluded their initial spares processes; therefore the information can now be declared public for further use in literature. Per the Turkish Air Force (student's sponsor), "the sensitivity of the information has been lifted".

JOSEPH J. PIGNATIELLO, JR.
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